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WOMEN ASTRONOMERS, (400 A. D.—1750).*

HERMAN S. DAVIS.

FOR POPULAR ASTRONOMY.

Le donne son venute in eccellenza
Di ciascun' arte ove hanno posto cura;
E qualunque all' istorie abbia avvertenza,
Ne sente ancor la fama non oscura.
Ariosto, Canto xx, 2.

Ariosto, in the canto from which the above quatrain was extracted, particularizes Harpalacy and Camilla as famous in warlike deeds and Sappho and Corinne

perche furon dotte,
Splendono illustri e mai non veggon notte.

Though at this day we might add to the former names that of Joan of Arc and to the latter more than one illustrious poetess, yet, reviewing the whole history of the world even to the present day, the comparative fewness of celebrated women in all the realms of art, literature, politics, and science would seem to indicate that it was mediæval chivalry and the poetic purpose which dictated to Ariosto the lines

E di lor opre belle e gloriose
Gran lume in tutto il monde si diffuse

rather than a love for historic truth. It is far from my purpose, however, to subject poetry to the standards of modern historic criticism. Fortunate is it for woman that she has so illustrious an advocate.

It is not in the sphere of independent work that women have been so active, but in their more quiet but effective influence over the men whom they have loved—their greatest work has been in aid to him. As Hamerton has said: "Not by adding to our knowledge but by understanding *us* have women been our greatest helpers," their sympathy and their encouragement urging to greater exertions and renewed endeavors. It is this characteristic which Shakespeare has portrayed in Lady Macbeth; this also

* Biographical Sketches, and a Review of Rebière's "Les Femmes dans la Science." (First Paper).

made the gatherings in the French *salons* of such wide-spread political importance in the past.

In astronomy we see illustrations of this at all times. Perhaps the discovery of the two satellites of Mars in 1877 is due as much to Mrs. ASAPH HALL as to her renowned husband. Wearied by ceaseless watching, discouraged by the lack of success in searching for that which he suspected but could not see, he would be sent back nightly to his task till at last on August 11 his vigils and her confidence were rewarded by a double prize.

Nearly at the same time, on the far-away, roller-bound island of Ascension, Mrs. DAVID GILL was contributing in like manner to the successful issue of her husband's expedition. She tells of the adventure in her charming *Six Months in Ascension*; how, night after night, the sky above Garrison on the north-western shore of the island where her husband had located his heliometer was overcast with clouds caused by trade winds blowing across Green Mountain; and how she, despite friendly advice and earnest entreaties, persisted in a midnight tramp across the 'clinker' to the western shore to prospect for a clearer sky—and found it. The adventure was a far more toilsome one than the bare mention of it would indicate. It required a bold heart and enthusiasm for science to initiate and execute the undertaking, as I can affirm from personal experience in following the same route in daylight twelve years later. The result was a change of location of the temporary Observatory and a continuous series of excellent observations for determination of the solar parallax.

Other women might also be included in this category of those who have thus added (by very great influence none the less valuable by being indirect) contributions to the progress of astronomy.

Independent investigators there have been, indeed, from Hypatia to Mary Somerville; but rarely. Nor is it at all to the discredit of woman as a class that such is the case, for whatever may be said on the subject of 'woman's sphere' in politics, it certainly is true that no one desires her to aid in the advance of science by such independent pedantry as Molière satirizes in his inimitable way in *Les Femmes Savantes*.* But when some individ-

* Butler in his *Hudibras* (II, 3) has also held up to ridicule one feminine pretender to astronomical learning—Sarah Jimmers, whom Lilly calls "Sarah Shelhorn, a great speculatrix."

A copper-plate, with almanacs Engraved upon't, with other knacks,
Of Booker's, Lilly's, *Sarah Jimmers*,
And blank schemes to discover nimmers;
A moon dial, with Napier's bones, And several constellation stones,
Engrav'd in planetary hours, That over mortals had strange powers,
To make'em thrive in law or trade, And stab or poison to evade.

ual woman of well balanced judgment shows a predilection for mathematics or astronomy and innate genius for higher research those characteristics will bear fruit despite discouragement. Of this truth Mary Somerville is perhaps the best example.

Without opening the discussion of higher education for women, which should be most heartily encouraged, I wish merely to pass in review, briefly, the lives of those women who have cultivated astronomy. This will be done in the form of a review of the book recently issued from the press of Nony & Cie, Paris: *Les Femmes dans la Science, notes recueillies, par* A. Rebière.

In this book the author has included 610 names of women who have in one way or another interested themselves in the various sciences. The remarks about these women are arranged in separate articles set in alphabetical order. Thus the volume is really a biographical dictionary. The dictionary proper comprises 285 pages and the remaining 74 pages are devoted to quotations, anecdotes, etc., from all sorts of authors and nearly every variety of literature, even including daily newspapers.

The book is very interesting, though I take issue with the author in his opinion that it would have been less readable had the arrangement of the dictionary been chronological rather than alphabetical. Certainly the most logical order is the chronological, then eight pages more would have sufficed for printing a complete index to facilitate the finding of any individual.

Of the 610 names almost exactly one-sixth belong to women who have been more or less intimately identified with astronomy. Of these many are so little known as to furnish less than a line of material for publication. The number of this kind is so large that it is likely to create the impression in the minds of some readers that the author had made a complete list of all women who have had their names in print as in any way connected with astronomy. Yet it would have been easy to double the number of names had that been the intention. Perhaps it would have been better if twenty per cent. had been omitted. Only the modesty of the title page, "notes recueillies" and recognition in the preface that there might be "inexactitudes et les omissions" justifies the inconsistency. Before the close of this article I shall show that there are a few errors, but of the omissions shall supply only those whose names have fallen in my way, so to speak.

It is proper to remark here, however, that on the whole Rebière has performed his self-appointed task remarkably well. He has collected a vast store of information and has given it to the

world in a sprightly book adorned with many portraits and facsimiles of handwritings. This book should be in every astronomer's library, especially for his wife and daughters to read.

The author has found authority for including among the ancient astronomers and astrologers the females:

AGANICE,	Egypt	ATHYRTA,	
AGLAONICE,	Thessaly	BERENICE,	Egypt
ARISTOCLE,	Greece	HIPPARCHIE,	
ATHENAIS,	Greece	OCCELO,	

But undoubtedly of all the female astronomers of antiquity the greatest was HYPATIA. Even with a due allowance for the fables which have gathered around her memory she was truly a very remarkable woman. Born in Alexandria, daughter of Theon, the librarian, himself a mathematician and astronomical commentator of no mean merit, judged by the times, she far surpassed him in her keenness of philosophical insight and power of disquisition; so that her fame spread abroad through the then known world. As Hypatia may be known to most readers entirely from the novel of this name by Charles Kingsley, it may be well to emphasize the fact that she is an historial personage. She was born about 370 A. D., and though in Alexandria by that date the mental strength of the Greeks, which gave birth to originality of thought and observation, had indeed passed away, yet Hypatia's learning and ability as a teacher present no unfavorable contrast with that of her masculine contemporaries. She wrote commentaries on the works of the ablest mathematicians who had preceded her; calculated astronomical tables, and publically lectured to throngs of eager students, at Alexandria, upon philosophy and science. But philosophy and science had fallen upon evil days. The population of that once famous seat of learning was now kept in continual turmoil by the bitter disputes and deadly animosities of three classes—the Christians, the Jews and the Pagans. The unscrupulous and fanatical Cyril gained the ascendancy for the Christians; and, probably at his instigation, a mob of vicious monks assailed the beautiful and cultured Hypatia as she was one day returning from her lecture-hall. With circumstances of the most fiendish barbarity they dragged her into a church where she was clubbed to death. Afterwards her corpse was disemmbered and one historian says that the mob actually scraped the flesh from the bones with oyster-shells and cast the remnants into a fire.

This murder of Hypatia in 415 A. D. is usually taken as mark-

ing the almost complete extinction of Greek science until the beginning of the eighth century when it was revived by the Arabs who, after their capture of Alexandria in 640 A. D., extended their dominion over all northern Africa and into Spain, whence emanated Greek scientific influence on Mediæval Europe.

It was not until the beginning of the twelfth century that another woman arose to vie with Hypatia for honors in science. St. Hildegarde (1099–1180), who founded the monastery of Mount St. Rupert near Bingen-on-the-Rhine, wrote a book in which Battandier has pointed out some marvelous statements: (1) that the Sun is in the midst of the firmament, retaining by his force the stars which move around him; (2) that when it is cold in the northern hemisphere it is warm in the southern, that the celestial temperature may thus be in equilibrium; (3) that the stars not only shine with unequal brilliancy but are themselves really unequal in magnitude; (4) that as blood moves in the veins (Harvey was not born until 1578!) and makes them pulsate, so do the stars move and send forth pulsations of light.

If even one-half of these marvelous statements are found in her writings as early as the twelfth century without putting too much of a modern interpretation upon her phraseology, this woman may well be classed with the great forerunners of modern astronomy,—with Copernicus, with Galileo, and with Newton; for she was three centuries earlier than the first of these.

It is greatly to be regretted, however, that Rebière did not give in a foot-note* the exact reading of her text. Perhaps he will do so in a later edition that each reader may form his own judgment on a matter so important.

* Personally I am not inclined to attach a very high value to the astronomical reveries of this Saint Her writings contain a general exposition of the science of the times, but most of it is neither original nor true. I quote three sentences that are, perhaps, the least tainted with pseudo-science.

. . . . Et primus splendore suo splendorem solis illustrat, secundus vero ardore suo ardorem soli administrat; tertius autem cursu suo cursum solis ad rectitudinem retentat. Cum his enim sol circumdatur, dirigitur et retinetur, quatenus firmamento omnique mundo temperamentum calore et spendore suo tribuat.

Pars I, Visio II, *Liber Divinor, oper. simplicis hominis.*

. . . . Sed et luna de aquosa humiditate, ac de nube quae sub ipsa est, et de aera qui super terram est, multo frigidior sole est; et sol multa perureret, si luna illi non resisteret, quoniam ardorem solis luna frigidio humere suo temperat. .

Pars I, Visio II, Ibidem.

Perhaps some one can bring himself to believe that the following reveals her knowledge of universal gravitation:

. . . . Homo quoque per oculos videt, per nasum odorat et per os gustat; sicut etiam per vim solis et lunae a summis stellis, quae ipsis cum ministerio adsunt, quidam radii aliquando in caetera sidera mittuntur, ita ut alterum lumen ab altero excitetur. . . . .

Pars I, Visio IV, Ibidem.

The Duchesse de Ferrare RENEE DE FRANCE (1510-1575) on page 231 and then SOPHIA BRAHE (1556-1643±) sister of Tycho, on page 43 come next in chronological order. Concerning Sophia reference is made to Bertrand's *Founders of Modern Astronomy* though probably the origin of every mention of her is one sentence by Gassendi in his *De Tychonis Brahei Vita*. He says simply: Ea fuit perita Matheseos, et Astronomiam cum diligeret, tum Astrologiam praesertim deperiit: unde et expeditissima in erigendis Thematibus fuit. How many girls in our Seminaries might not have their names enrolled among astronomers as justifiably—if only their brothers should prove themselves to be Tychos!

MARIA CUNITZ was the oldest daughter of Henry Cunitz, a physician of Schweidnitz in Silesia, where she was born about 1610. From girlhood she was inclined to a studious life. After learning history and seven languages she gave special attention to astronomy. She found it continually necessary to defend herself against the general prejudice towards literary women; but both Kästner and Wolf remark with justice that her own life's work was her best vindication. In 1630 she married Elias von Löwen, a physician of Pitschensis. He was also an amateur of astronomy. With some idea of the need for more simple planetary tables he induced her to compose a compendium to the Rudolphine Tables. This she did with his assistance, though not, as sometimes supposed, under his direction. In her preface she gives her husband credit for his services but assumes for herself the responsibility. This is one of the instances where love of science was innate and not acquired from the husband. The magnitude of her labor on these Tables can only be imagined when it is remembered that she did not use logarithms. Unfortunately, while detecting many mistakes in her original sources, she likewise committed many errors herself. Her Tables were a simplification of the Keplerian principally because she neglected small terms in the formulas, such, for example, as the variation of the Sun's distance. Nevertheless, when they were published in 1650 under the title *Urania Propitia* they testified to the genius of a woman who must be admired for her devotion to studies so arduous and to problems so abstruse.

The greater part of this work it must be remembered, too, was prosecuted in the midst of war and in Poland, far away from her home, whence she had fled during the Franco-German war. In 1662 she became a widow, and two years later died, on August 22, while again in flight from the ravages of war.

In the picture on page 57 of Hevelius's very rare book, the *Machinae Celestiae*, may be found represented his own conception of the appearance of his second wife, Madame ELISABETH (or as some authors say, Margarethe) HEVELIUS, née Korpmann. At the time of her marriage she was sixteen years old and famous for her beauty. Indeed it is probably an allusion to her beauty that Westphal makes when he remarks that a comparison of her picture in the first part of the book with that in the last part shows every evidence that they did not both sit up every night to star-gaze. Doubtless, as Hevelius was his own engraver, he did full justice in both pictures to his wife's reputed beauty. Yet Maedler says she is pictured *in effigie* standing in front of the telescope. However that may be, it is true that she rendered her husband the greatest assistance in his observing and without that assistance his life, so fraught with troubles and disappointments, could never have reached the degree of success it otherwise did.

Hevelius was an eminent and wealthy amateur of Danzig. At the same time that Maria Cunitz in Silesia had undertaken a revision of the Rudolphine Tables, Hevelius was likewise conceiving the desire of devoting himself to their revision. Her plan was by a new reduction of old observations: his, by making new observations that should be more accurate. Each was adapting self to circumstances. She was without instruments and without wealth, hence devoted herself to computations which she could do. He was wealthy and in consequence bought instruments and built an Observatory on the roof of his house. After numerous delays which occupied as many as thirteen years he at last, in 1652, began observing for a catalogue of fixed stars. He was assisted by a young man named Kretzmer who had a remarkable taste for astronomy, but whose career was cut short in three years by death. His place was then filled by another assistant who lived only a year. *His* successor in turn died in a few days. Hevelius, thus thoroughly discouraged, then impressed his "printers' devil" into the service of the heavenly science—for besides the usual outfit of astronomical instruments he had also provided himself with a printing outfit that he might the more readily and satisfactorially publish his results to the world. This fellow was probably found to give rather precarious aid for we notice that one household servant after another was tried until finally his wife came to his relief and proved to be the very best of them all.

It is needless to tell how the fruits of their many years of labor

were lost in 1679 by the great fire which destroyed nearly the whole city including his Observatory and records and nearly all the printed copies of the *Machinae Celestae*. Eight years afterwards Hevelius died; some say of a broken heart. After his death his widow published the *Prodromus Astronomicæ* and *Firmamentum Sobieskanum*. The latter she dedicated to John Sobieski, king of Poland; and in it, under the appellation of Scutum Sobieskanum, she* named a constellation in his honor. How long Madame Hevelius survived her husband is not known, nor has she left any further mark of originality in science or literature.

It is of interest to note that this catalogue in whose construction Madame Hevelius so nobly assisted contains the position of 1888 stars. This is the largest number contained in any catalogue from observations with instruments without telescopes, as it is also the last catalogue so constructed. Thus the career of this devoted couple may be taken as marking the close of the Transitional Period between mediæval and modern astronomy.

While Maria Cunitz was prosecuting her work under the gravest difficulties arising from the Franco-German War and even lost her life as an indirect result of that prolonged turmoil, we read the equally sad story on the French side. How JEANNE DUMEE at Paris, in the seventeenth year of her age, not in romanticism but in stern reality, sent her soldier-husband off to the battle field, and thereafter as a solace to her solitude devoted her attention to astronomy,—having previously for some years devoted her leisure to refined studies. History tells not the end of his career. But at any rate the separation lasted long enough for her to write a book on "the opinion of Copernicus concerning the mobility of the earth," wherein with masterful hand she draws forth arguments for and against the Copernican system, and one by one shows how observations of Venus and Jupiter and his rotation and the revolution of his satellites prove the motion of the Earth and the validity of Copernicus' assumptions.

* The accompanying illustration (see frontispiece) is reproduced from the *Firmamentum Sobieskanum*. While it is true that this book was a posthumous publication and that the preface was written by the widow, Madame Elisabeth, the illustration itself (especially when judged in conjunction with the text of the book) leaves little doubt that the happy thought of honoring a patron by this new constellation was a scheme well thought out and really executed by Hevelius himself. It is Hevelius and not the Madame whom the picture represents as humbly offering his two new constellations to the kindly consideration of the greatest astronomers who had preceded him. The angels herald abroad praise and glory. Ptolemy's interest, Hipparchus' thoughtful attention, Timocharis' surprise, Tycho's bewilderment, are all manifest in the countenance or manner of those distinguished personages presided over by the goddess Urania. The original engraving is probably even the handiwork of Hevelius,—it is finished in such elegant detail.

MARIA CLARA MULLER, née Eimmart, was the daughter of George Christophe Eimmart, an engraver and painter of Nuremburg. She was born in 1676. Her father's profession was a lucrative one but he spent all his earnings in the purchase of astronomical instruments. He was a diligent observer and published his results in various memoirs and transactions of societies. At his death many volumes remained unpublished. Among these was *Micrographia stellarum phases lunae ultra 300* for which the illustrations were drawn from telescopic observations by his daughter Maria Clara. Maria's skill as an engraver was also of considerable assistance to her father.

Maria married Johann Heinrich Müller who was her father's assistant engraver. But Müller had been so influenced by the family love for astronomy that he became a diligent amateur and afterwards a professor at Altorf, where he used his manual skill in depicting comets, sun-spots and lunar mountains, aided by his talented wife.

With these in their earlier Nuremburg home were associated the two Rost brothers, novelists and astronomers; also Wurtzelbauer, and Doppelmayer an historian of astronomy. Happy gatherings must these have formed in the workshop and in the Observatory under the watchful eye of father Eimmart and the bewitching smile of daughter Clara. History does not state how many of these students of the heavens were lured to a contemplation of the celestial by their respect and admiration for the graceful and fair Diana of the engravers' bench. Maria Clara died 28 Oct., 1707 (not 1717 as given by Rebière).

MARIE MARGARETHE KIRCH, née Winckelmann was born in upper Lusatia in 1670. Her father was a minister of the Gospel of Panitzch near Leipzig. By nature and also by the training of the peasant astronomer, Christoph Arnold who discovered the comet of 1683, she was such a lover of astronomy that when she became the wife of Gottfried Kirch she was easily able to profit by her husband's further instruction and thus render him considerable assistance both in observing and in computing. Several almanacs and other books were the results of their labors up to her husband's death in 1710.

In 1694 Madame Kirch became the mother of Christfried Kirch who followed the precedent of his parents in profession. As assistant to his mother in preparation of almanacs which she continued to issue after her husband's death, Christfried won sufficient reputation to justify his election to the directorship of

the Observatory of Berlin where he assiduously observed for many years—now in turn assisted by his mother and his eldest sister.

This sister, CHRISTINE KIRCH, had previously been an assistant in the private Observatory of Baron von Krosigk. On the death of the baron she went to live with her brother. Christine died in 1820. Her niece was the wife of Bode, who for so many years published the *Berliner Jahrbuch*.

THERESA and MADELINE MANFREDI, the sisters of Eustachio Manfredi (1674-1739) who was the director of the Observatory of Bologne, Italy, assisted him for many years in the computation of the Ephemerides of Bologne. Maedler mentions (though pehaps incorrectly) a third sister, AGNES, who also rendered assistance in the calculations.

But not alone by patient toil has woman been content to leave her name in astronomical literature. While these sisters in Italy were laboring with the Arabic characters Emilie de Bréteuil, the MARQUISE DU CHATELET, in France was astonishing all Europe by her sparkling originality and brilliant genius. The wife of a marquis but paramour of a philosopher, she is as noted for her depth of scientific intellect as she is notorious for her shallowness of decent morality. She was born at Paris in 1706 and early showed mathematical proclivities. During her short life she published a large number of books and by many writers has been classed with her two renowned teachers and correspondents, Maupertuis and Clairaut. But the work by which she is best known is her translation and popular exposition of Newton's *Principia*, which she was among the very first of continental mathematicians to properly appreciate. Rebière devotes to this remarkable woman eleven pages of his book, inclusive of her portrait and a facsimile of her manuscript and of the title-page of her *Institutions de Physique*, published when she was 34 years of age. She died 10 August, 1749.

COLUMBIA UNIVERSITY, New York City.
March, 1898.

(TO BE CONTINUED.)

ASTRONOMICAL MYTHS—ASTROLOGY.

THOS. LINDSAY.

FOR POPULAR ASTRONOMY.

Some time ago at a meeting of the Astronomical and Physical Society of Toronto, a member asked whether anyone present could explain the exact meaning of the phrase "in the ascendant," which has now passed into our common language. Two or three of the friends looked at me and I had to acknowledge my guilt—was obliged to confess that I did know, but at the same time made a feeble effort to apologize for my superior knowledge and wound up by freely admitting that I had been foolish enough to waste some time on the study of astrology—long ago, when somewhat younger than now. But no one has asked me to address the readers of this Journal on the subject, and some apology is needed for inflicting it upon them. Will it suffice to say that the science being very old, should be treated with some little respect? Of course we do not pardon an old fraud because of his years, rather the contrary; but we are many centuries past the astrology days and it will be pretty hard for us to prove positively that it was a very bad fraud. Perhaps it was something like the departmental store, of questionable economic worth—yet the people want it. Whoever commenced it knew what he was about, knew human nature pretty well, and if the test of any great work of genius is universality, then astrology was a great science for it aimed at quieting that universal unrest caused by man's desire to know the future. In its miserable failure to do this we see only another evidence of the beneficence of the Creator.

It is a very common introduction to the study of astronomy proper to say that in the beginning men watched the movements of the planets, believing that these were intimately connected with human events; and that from a false system there sprang up the sublime science we now love so well. Now my own interest in astrology lies in this: it was a desire to know how in the name of all that was sensible or silly, man ever could invent a method of telling the future, that led me to read such departments of practical astronomy as were not too difficult for one with only an elementary knowledge of mathematics. It need hardly be said whence this desire; from reading Guy Mannering of course, just as you did, and you, for I believe that nowhere is the wizard of the north better known than in the United States. You remember how delighted you were with the story of the young heir of

Ellangowan and how marvelous you thought the skill of Mannering in foretelling what would happen to the boy. Perhaps, however, you were not curious to know how he did it. Well, you see I was, and that is the whole story.

I learned long afterward that Scott's use of the technical words of the science was very correct, but in those days of course they were quite mysterious. Books giving some account of astrological lore have never been scarce, but many of us have gone hunting round for information that was really quite accessible, so it was a matter of curiosity with me for many a long day. At last however I struck it lucky. I was down in New Orleans at the time, in the good ship D. W. Chapman, of Damariscotta, Me., and on the eve of sailing, while strolling through the city, ran up against a book-stall. That is a thing I never could pass, and on this occasion, sure enough, among the mathematical books was a copy of "Lilly's Astrology, by Zadkiel." Quite providential I thought it was; the hunt for a proper book on this subject had been a long one, but successful at last. The price asked was a good deal more than the regular catalogue figure, for the work was not at all rare, but the bookseller no doubt "saw me coming."

The volume became mine, at any rate, and great fun we had with it; for three of my most companionable shipmates had to be told what I was reading in the dog watches and at all times off duty. I remember the boys well; there was Charley James for one, a young Virginian, whose comments were few, between the whiffs of his pipe; Charley perhaps hardly knew just "where I was at." Then there was Omar Chapman, hailing from Damariscotta, not long from College; Omar was the best educated among us and appreciated all the amusement there was to be had in discussing nonsense. Quite recently I heard about Omar, he was out Japan way, master of the ship J. R. Kelly. How he clung to a sea life so long is hard to understand; however there is a wide field for the sailor who is also a gentleman, and I warrant Omar has found his sphere. The other lad was Frank Cottar, also from Damariscotta, one of a family of sea-dogs. Frank was rather more prosaic than any of us and would take me seriously; consequently he was always being riled at what he styled "confounded rot." Our conversation might run, for instance, on such an out of the way subject as birthmarks:

"Now look here Frank I know all about what causes things of that kind; now take moles"—

"Well, let's take moles."

"Exactly; now one man has a mole on his left leg and another

has one under his right ear; that's because one man is born when Mars is just about ———"

"Scat!"

That was enough for Frank. He could only reply by reaching for a boot. Poor Frank, he was another gentleman sailor, but not of strong physique; he was gathered to the great majority some years ago.

But amusement was not the only thing supplied by Zadkiel. The author who adopted this pseudonym was a lieutenant in the English navy and it was easily seen was well up in elementary practical astronomy. Some of his formulæ were models of conciseness, easily worked, and one could readily learn first how to construct a "horoscope" and then how to interpret. Just a few examples of the latter and the whole secret was laid bare, there were so many things to be predicted that the marvel would be if a great deal did not "come true." In olden times the astrologers would not fail to make most of their fortunate divinations, and would studiously avoid reference to failures, or at the worst, find a host of excuses; some other planet which had been overlooked in the first calculation, had exerted its influence and so on.

Zadkiel's method of dividing the heavens into twelve parts was a little complicated, and admittedly modern, but "the first house" or "ascendant" or simply the "rising point" of the zodiac at a given moment, in a nativity the moment of birth, was easily calculated. Of course this was the point which the native had to watch all through his life. If a bad planet was on it or near it look out for danger; if one of the "benefics" happened around then all was well, and so on. Reference to a globe will readily show that the rising point for a given latitude requires for solution only a knowledge of the right ascension of the meridian; the obliquity of the ecliptic being of course known. The predicting business was something like this: Suppose the rising point to be 95° from Saturn; advance the point 5° then it is in "quartile" with Saturn, a very bad "aspect." Now find how long it will take for the Sun to move 5°, then say one year for each day and one month for each two hours and you have the time; the simplest thing in the world. This is precisely how Mannering might have foretold the troubles in store for Harry Bertram. The 5° would be technically the "arc of direction" and the method of finding it was a little more complicated than by taking degrees of longitude, but the above is near enough for the purpose at present. You might advance the Moon or the Sun or the meridian in the same way, so that practically the number of events to be fore-

told would be legion. Then again perhaps at the time predicted there might be some planet hovering around tending to aid or destroy the "aspect" in its effect. This necessitated finding how to approximately name the place of the planet in the future. I remember being delighted to find that this also was not a difficult matter, using mean revolutions, and in fact was well pleased with Zadkiel for having given me that hint.

It is not to be supposed that those who practice this ridiculous system today are all expert at astronomical calculations. In fact a man would earn a very meagre living if he followed all Zadkiel's rules every time he "cast a nativity." I know something about this; I worked at a horoscope at odd times, off and on, for two years so as to have it complete—just following an interesting event in our own house. About the end of that time another event occurred and I quit right then and there. The up-to-date method no doubt is to use a globe to roughly get the ascendant, divide by circles through the poles, and read away—the faculty of invention being the only one required. As the readers of this Journal doubtless know, there are yet a few "astrologists," (they have modernized the ending) doing business in the large cities and if they do business they must have clients. The fact remains too that reputable serials have admitted this nonsense into their pages. The Boston *Arena* and the great English *Review of Reviews* have both been guilty. I used to think a lot of W. T. Stead at one time but after reading his editorial matter on astrology I could be fooled no longer. As the old dock-master said "Them 'ere wharfingers is a set of rogues and robbers, I know 'em well, I was one myself for twenty years."

Upon the old astrologers however, I trust I have never been severe. There are a few things that do point to what may have started the science. The sudden, even if only momentary, elevations of spirits when the Sun breaks out upon us, after a cloudy, depressing (you see we must use this word) spell of weather, requires explanation. I have no doubt there is a genuine scientific reason for this, but the old philosophers did not know anything about molecules and nerves. So it was the Sun did it, because he was just there for that purpose. In fact we have only to remember that Kepler was an astrologer and our hearts warm a little to the pioneers who, albeit through gross error, led us to truth.

TORONTO.

COMET FAMILIES AND THE CONSTITUTION OF COMETS III.

W. W. PAYNE.

In the first number of this series of brief articles, we gave a short review of the comet families belonging to the planets Jupiter, Saturn and Uranus. In the second one, we presented the family of Neptune, giving somewhat at length the characteristics pertaining to the orbit of the Halley Comet as it was known in 1835, and, as it has been since verified.

We should now give some idea of the physical appearance of the comet at that return, that it may be compared with other notable ones, and that its striking features may be remembered when the comet shall visit our solar system again about the year 1911.

Previous to the appearance of this comet in 1835, astronomers believed that its return would afford an opportunity for obtaining some knowledge of its physical constitution, which would serve as a basis for a theory in regard to comets in general; for previous to this time, the comet was little else than an object of terror to most people on account of the prevailing superstitions which comets had aroused through all time before. It is easy to understand how such a belief would start, and grow under the circumstances, the simple and sufficient reason being the lack of knowledge about the real nature of the comet. It is also probable that the educated of the priestly class sometimes awakened great alarm by announcing them as harbingers of evil, like that of famine, pestilence or war.

Above all things, then, it was needful that the astronomer learn something definite about the comet, if possible, to supply a real want of information so evident everywhere. It was not expected that this comet would show great physical changes, as it approached the Sun, yet it was hoped that enough could be seen, even in a quiescent state, to give some data by the aid of the telescope to meet the expectations of scholars.

It is a noteworthy fact that as soon as the comet came into view, strange and important changes were observed very generally with much interest. Such astronomers as Bessel, Schwabe, Struve, Maclear and Herschel studied the comet with a zeal and fidelity worthy of the great opportunity offered.

These striking changes in the comet's appearance began in the early part of October, 1835, and were first noticed as the tail began to form. October 2 the nucleus, which had previously been

faint and small, suddenly grew brighter, and became active, on its sunward side, throwing out streams of light, that one writer described, as "fiery matter issuing from the crater of a volcano." Two days later, by the aid of high telescopic power, the central part of the head of the comet had a very curious appearance. The nucleus was not circular, as usual, but elongated, some five or six times as great in one direction as in the other. It was said "to resemble burning coal, from which there issued, in a direction nearly opposite to that of the tail a divergent flame, varying in intensity, in form, and in direction. Occasionally it appeared doubled, and seemed to indicate that luminous gas was issuing from the nucleus."*

October 15, Arago at Paris observed a very singular change in the appearance of the head of the comet. The same changes at this time was also seen by others. The nucleus had brightened and extended itself in the form of a luminous sector, whose central point of activity was a little south of the middle point in the head opposite the tail. This sector was much brighter than the nebulosity of any part of the comet outside of it. From what had happened during the early days of this month it was impossible to predict what great change would next follow, and observers were not surprised, if they were disappointed, to find on the following evening that the luminous sector had entirely disappeared; and that, at another point exactly opposite to the axis of the tail, a new sector had formed, which was brighter and more extended than the one observed the evening before. This sector seemed to communicate with the center of activity in the comet's head by two very bright lines which doubtless were the channels through which immense masses of cometary matter flowed to produce these rapid and remarkable changes which had been in progress for two or three days. During the next two days the splendor and the activity of the head rapidly diminished and the entire comet was fading, in such a way as to indicate that its end of visibility might be drawing near. But not so, for on Oct. 21 three bright sectors again appeared in the comet's head exhibiting similar phenomena to those already described, but which lasted for two days only, before they totally vanished, and, as a consequence, the whole aspect of the comet was again suddenly and very completely changed. The nucleus, which before had been bright and well defined had become diffuse, faint and large, and brighter in the nebulosity of the head on the eastern side than on the western.

* Watson's Popular Treatise on Comets, p. 207.

THE SUN'S HEAT.

ANNE SEWELL YOUNG.

FOR POPULAR ASTRONOMY.

In a popular lecture* delivered at Königsberg, February 7th, 1854, Professor Helmholtz explained how the contraction of the Sun's mass under the action of gravitation is sufficient to account for all the Sun's heat. His method of obtaining this result may not be familiar to all the readers of POPULAR ASTRONOMY.

If we suppose our solar system to have reached its present state after a long process of contraction from a highly diffused nebula, an enormous amount of energy will be manifested as heat. The potential energy of a unit of the Sun's mass is equal to the amount of work done in moving it from infinity to its present position; letting U_p represent the potential of a unit of mass, $d(U_p) = \frac{d^2r}{dt^2}\,dr$;

but $$\frac{d^2r}{dt^2} = -\frac{M}{r^2} \therefore d(U_p) = -\frac{M}{r^2}\,dr.$$

$$U_p = -M\int_r^\infty \frac{dr}{r^2} = -\frac{M}{r}.$$

He considered the Sun as homogeneous, therefore $M = \frac{4}{3}\pi\sigma r^3$; $U_p = -\frac{4}{3}\pi\sigma r^2$. The volume of a shell of unit thickness would be $4\pi\sigma r^2$, and if U_v represent the potential energy of the entire mass,

$$d(U_v) = -\frac{16}{3}\pi^2\sigma^2 r^4\,dr.$$

$$U_v = -\frac{16}{15}\pi^2\sigma^2 r^5, \text{ which may be written}$$

$$-\frac{3}{5}\frac{M^2}{r}. \quad (A)$$

Since $g = \frac{m}{R^2}$, or $\frac{R^2 g}{m} = 1$, we may also write $U_v = \frac{3}{5}\frac{M^2}{m}\frac{R^2 g}{r}$.

The amount of heat required to raise a mass M to a given temperature t is $M\eta t$ (η = specific heat) and its mechanical equivalent is $M\eta t.\,Ag$. Now the other mechanical forces having their source in the potential energy of the Sun's mass, are the vis viva of the rotation of the planets and of their revolution around the

* Philosophical Magazine, 1856, "On the Interaction of Natural Forces."

Sun. Professor Helmholtz estimated the maximum value of the vis viva of planetary revolution as only $\frac{1}{454}$ of the potential energy, while rotation gives a wholly inappreciable fraction. We shall commit a very small error therefore in applying to the Sun the equation

$$U_v = \frac{3}{5}\frac{M^2}{m}\frac{R^2 g}{r} = M\eta t.\ Ag,$$

$$\text{or, } t = \frac{3}{5}\frac{M}{r}\cdot\frac{1}{\eta}\cdot\frac{R^2}{m}\cdot\frac{1}{A}, \quad (B)$$

in which t represents the number of degrees which the temperature of a given body would be raised in contracting from infinity to the radius r. If we wish to find t between the limits r_0 and r_1 we may write $t = \frac{3}{5}\frac{MR^2}{m\eta A r_0}\left(1 - \frac{r_0}{r_1}\right)$.

The only two variables in equation B are r and A, so that we may write $rt = K$, an equation whose locus is an hyperbola referred to its rectilinear asymptotes.

We find that the Sun in contracting from infinity to a radius equal to that of Neptune's orbit would have generated enough heat to raise the temperature of an equal mass of water 4130° C., at Jupiter's orbit 24,440°, while in reaching its present size the temperature would have been raised 27,250,000°. The accompanying diagram shows the relative amounts of heat which would have been produced when the Sun's radius was equal to that of each of the planetary orbits. The values of t are given in round numbers only.

If, as Pouillét estimated, the Sun is radiating enough heat to reduce its temperature 1°.25 C. each year, this 27,250,000° would be sufficient to last eighteen million years. Professor Helmholtz estimated the Sun's possible age as twenty-two million years. A contraction of $\frac{1}{10000}$ of the Sun's diameter would furnish enough heat to raise an equal mass of water 2725°, which would last over 2,000 years. The Sun's diameter is in round numbers 2000″, so that a contraction of .2″ in 2000 years would be sufficient to account for the Sun's heat. It would be 10000 years before the Sun's diameter would show a change of 1″, so we cannot expect to verify the theory by observation at present.

Referring to our curve, we note that when the contracting nebulous mass extended as far as Jupiter's present orbit, t was a small quantity. The outer planets are supposed to be hot; is it therefore necessary to endow the original mass with a high degree of heat? We find that the contraction of Jupiter from a density

the same as that of the Sun's mass when its diameter was equal to that of Jupiter's orbit, would give $t = 261000°$ ($\eta = 1$); Saturn's mass is much less and yet here we find $t = 93000°$, while Neptune gives $t = 34750°$. Even our own little planet could have raised the temperature of an equal mass of water 8600° in this way. Add to these numbers those indicating the heat of the original mass at the corresponding stages, and our question has found its answer.

The above estimates of heat were made with the assumption that the Sun's mass is homogeneous throughout, whereas it is probable that its density increases as we approach the centre. We have no means of determining what the law of density really is, but let us assume it to be represented by the equation $\sigma = \frac{1}{r^2}$ and investigate the effect upon t. (Of course this law could not be strictly true, as it would make the centre of infinite density).

Using the same notation as before,

$$d(U_p) = -\frac{Mdr}{r^2};\ U_p = -\frac{M}{r}.$$

$dM = \sigma r^2\, dr\, .\, d\varphi\, .\, \sin\theta d\theta.$

$$M = \int_0^r \int_0^{2\pi} \int_0^{\pi} dr\, .\, d\varphi\, .\, \sin\theta d\theta = 4\pi r.$$

This result can be obtained at a glance if we note that the mass of each infinitesimal shell would be $4\pi dr$.

$$U_p = -\frac{M}{r} = -4\pi.$$

The mass of a shell of unit thickness would be 4π; then

$$d(U_v) = -16\,\pi^2\, dr;\ U_v = -16\,\pi^2 r = -\frac{M^2}{r}.$$

Our equation for t is therefore the same as before with the exception of the numerical factor $\frac{3}{5}$, which is now unity. That is, if the density of the Sun varied inversely as the square of the distance from the centre, our computed values of t would have to be multiplied by the fraction $\frac{5}{3}$. This result leads us to infer that if the density increases toward the centre, t will also increase.

If we assume as our law of density $\sigma = \frac{1}{r^n}$, the result is more complicated.

We have then $dM = \frac{1}{r^{n-2}}\, dr \,.\, d\varphi \,.\, \sin\theta d\theta$ which gives

$$M = 4\pi \int_{r_1}^{r_2} \frac{dr}{r^{n-2}} = -\frac{4\pi}{(n-3)\, r^{n-3}}\Big]_{r_1}^{r_2}$$

In order to avoid infinities, let us imagine at the centre a small incompressible mass of radius ar. Using ar for the lower limit we arrive at a result analogous in form to that obtained in the two cases already considered. In this discussion we assume a to be so small that the mass of this centre may be neglected in computing the potential of the Sun's mass.

We take accordingly as the value of M,

$$-\frac{4\pi}{(n-3)\, r^{n-3}}\Big]_{ar}^{r} = \frac{4\pi\,(1-a^{n-3})}{(a^{n-3})\,(n-3)\,(r^{n-3})}$$

$$U_p = -\frac{4\pi\,(1-a^{n-3})}{(a^{n-3})\,(n-3)\,(r^{n-3})}$$

For the sake of simplicity let us suppose a unit shell to be homogeneous, and its mass therefore equal to $\frac{4\pi}{r^{n-2}}$;

$$\text{then } d\,(U_v) = -\frac{4\pi\,(1-a^{n-3})}{(a^{n-3})\,(n-3)\,(r^{n-2})} \times \frac{4\pi\, dr}{r^{n-2}}$$

$$= \frac{-16\pi^2\,(1-a^{n-3})}{(n-3)\,(a^{n-3})\,(r^{2n-4})}\, dr$$

$$U_v = \frac{16\pi^2\,(1-a^{n-3})}{(n-3)\,(2n-5)\,(a^{n-3})\,(r^{2n-5})}\Big]_{ar}^{r}$$

$$= -\frac{(n-3)\,(1-a^{2n-5})}{(2n-5)\,(1-a^{n-3})\,(a^{n-2})}\,\frac{M^2}{r}$$

Therefore if the Sun's density varied inversely as the nth power of its distance from the centre, we would substitute for the fraction $\frac{3}{5}$ in our original equation for t,

$$\frac{(n-3)\,(1-a^{2n-5})}{(1-a^{n-3})\,(2n-5)\,(a^{n-2})}.$$

The two cases already considered agree with this result, letting a equal zero in each case and n equal respectively 0 and 2. The numerical value of this factor will depend very largely upon $\frac{1}{a^{n-2}}$, whose value increases rapidly as n increases, since a is a very small fraction.

We have therefore shown that the amount of heat generated by the contraction of a mass whose density increases toward the centre is greater than that produced by a homogeneous mass.

April 5th, 1898, UNIVERSITY OF CHICAGO.

A NEW GRAPHICAL METHOD OF DETERMINING THE ELEMENTS OF A DOUBLE-STAR ORBIT.

HENRY NORRIS RUSSELL.

For Popular Astronomy.

The determination of the elements of the true orbit of a double star, when the apparent ellipse has been obtained, demands the solution of the following geometrical problem. Given the orthogonal projection of an ellipse, and of one of its foci, upon the plane of vision; required the elements of the ellipse.

The apparent orbit is an ellipse; but the large star is usually not in the focus. In the apparent ellipse the diameter which passes through the large star is the projection of the major axis of the true orbit, and the conjugate diameter is that of the true minor axis. The ratio between the distance of the star from the centre of the apparent ellipse and the semi-diameter which passes through them is the eccentricity of the true orbit.

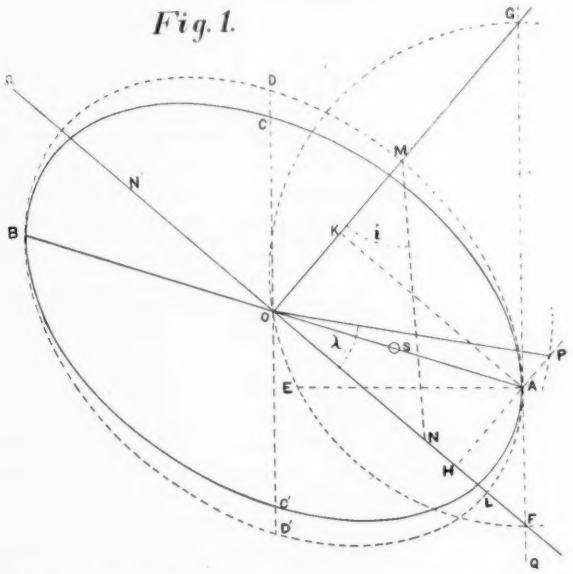
If we bear these relations in mind, the following simple considerations lead us to a purely geometrical solution of the problem.

Let us suppose the circumscribing circle of the true ellipse drawn in its plane, and projected upon that of the apparent orbit. It follows from the relations of the ellipse to its circumscribing circle that this projection will be an ellipse concentric with the apparent orbit. This may be called the auxiliary ellipse. It will touch the apparent ellipse at the ends of the projected major axis, and cut the projected minor axis in two points whose distances from the centre of the apparent ellipse are to the semi-diameter on which produced they lie, as the major axis of the true orbit is to the minor. The tangents to the two ellipses at the points where they are cut by the projected minor axis are parallel. It appears thus that the auxiliary ellipse has the projected major axis as a diameter, and as conjugate to it the projected minor axis increased in the ratio of the axes of the true ellipse. But this ratio is known, since the eccentricity of the true ellipse is known. It is $1 : \sqrt{1 - e^2}$. We can therefore construct the auxiliary ellipse, since we can determine two conjugate diameters in magnitude and position.

But since the auxiliary ellipse is the projection of a circle, its major axis must correspond to that diameter of the circle which is not shortened by projection, and must therefore be parallel to the line of nodes of the plane of the circle, and equal in length to

a diameter of the circle. But the circle of which the auxiliary ellipse is a projection has a radius equal to the semi-major axis of the true ellipse. Therefore the major axis of the auxiliary ellipse is parallel to the line of nodes of the true orbit, and is equal in length to its major axis. Again, since the minor axis of the auxiliary ellipse corresponds to the diameter of the circle which is most shortened by projection, its ratio to the major axis is evidently the cosine of the angle between the plane of the circumscribing circle and the plane of sight, *i. e.* the inclination of the true orbit.

Fig. 1.



The actual construction may be carried out as follows: Let $ACBC'$ (Fig. 1) be the apparent ellipse, O its centre, and S the large star. AB, which passes through O and S, is then the projected major axis. Construct the diameter OCC' conjugate to AOB. This may be simply done by drawing any chord of the ellipse parallel to AB and finding its middle point. The conjugate diameter passes through O and this point.

Determine on OCC' two points D and D' such that $OD = OD'$, and $OD : OC = a : b = 1 : \sqrt{1-e^2} = OA : \sqrt{OA^2 - OS^2}$, (where a and b are the semi-axes of the true orbit and e its eccentricity). OA and OD are then conjugate semi-diameters of the auxiliary ellipse.

A simple and direct construction for the axes of an ellipse of which two conjugate semi-diameters are given, may be found in Cremona's "Elements of Projective Geometry" (Oxford 1893) p. 232. It is this: Let OA and OD be the conjugate semi-diameters. Draw AQ parallel to OD. It will be the tangent at A. Draw a perpendicular to AQ at A, and on it take $AE = OD$. Draw a circle with centre on AQ passing through O and E. Let its intersections with AQ be F and G. Then OF and OG are the positions of the axes. Draw AH perpendicular to OF, and AK perpendicular to OG. Take OL a mean proportional between OF and OH and OM a mean proportional between OK and OG. Then OL and OM are the semi-axes of the auxiliary ellipse. (For proof see Cremona.) The foci N and N' of the auxiliary ellipse may now be constructed (by taking $MN = OL$), and the ellipse drawn. This affords a valuable check on the construction, since the ellipse, if correctly determined, will pass through L, M and D, and touch the apparent ellipse at A.

It now follows from our theory that OL is parallel to the line of nodes of the true orbit, that the length OL is a, the semi-major axis of the true orbit, and that if i is the inclination of the true orbit, $\cos i = \frac{OM}{OL}$. If we join MN, i is the angle OMN, since $MN = OL$.

As it cannot be determined which of the two nodes is really the ascending node, the convention is made that we call that node which has the smaller position-angle the "ascending node."

It only remains to find λ, the angle at the centre of the true orbit between the node and the periastron. Since OL is parallel to the line of nodes, and the true orbit is orthogonally projected on the plane of sight, we may obtain it from the apparent orbit by increasing all distances perpendicular to OL in the ratio $1 : \cos i$, that is, $OL : OM$, and leaving unchanged all distances parallel to OL. If we therefore increase AH in this ratio, so that $HP : HA = OL : OM$, then HOP will be the angle at the centre of the true orbit between a node and the periastron. (As the angle conventionally called λ is reckoned from the "ascending node" in the direction of the stars' motion, the angle HOP is not necessarily λ, but may be $180° \pm \lambda$ or $360 - \lambda$). We see also that OP should be equal in length to a, that is, to OL, which gives us a check upon the construction of P.

As e was known from the apparent orbit, and as we have determined a, Ω, i and λ, the elements of the orbit are all determined, and by a purely geometrical process.

The period and periastron passage of the small star are determined in the usual way by measurement of the areas swept over by the radius vector. Since by the theory of central forces equal areas are swept over in equal times, if we measure with the planimeter the area of the apparent orbit, and of the sector described in a known time, say ten years, we shall have the proportion: Period : 10 yrs :: area of orbit : area of sector. Similarly the time required to describe the sector between the place at a known time and the periastron is to 10 yrs. as the area of the sector is to the area described in 10 yrs.

The method described in this article is capable of considerable accuracy, especially if the constructions be made on both sides of the centre of the figure. It also admits of simple and accurate checks (by drawing the auxiliary ellipse, and by verifying that OP equals OL.) The errors of the graphical process are not large enough to be of any moment in the present state of double star measurement.

The ephemeris for the small star may also be obtained graphically, as follows: Since we know the eccentricity, the period, and the periastron passage, we can determine the eccentric anomaly of the small star in the true orbit at any given time, preferably by means of a curve of sines. (See See's "Evolution of the Stellar Systems," p. 60).

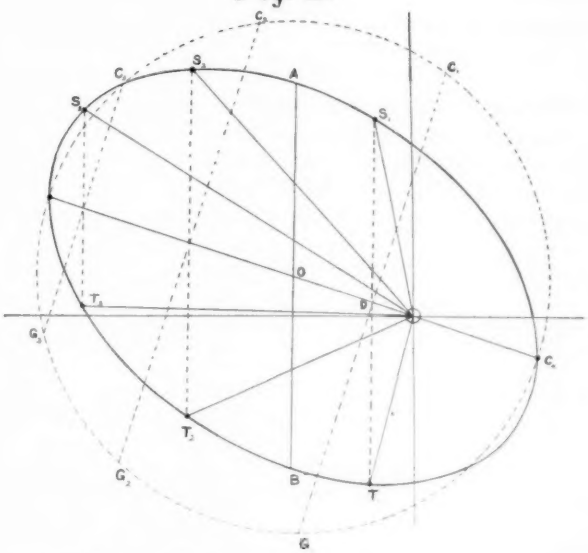
In the true orbit the ratio of the distance from its centre of the foot of the perpendicular from the small star upon the major axis, to the semi-major axis itself, is equal to the cosine of the eccentric anomaly. The ratio of the corresponding distances in the apparent orbit must be the same, since they are segments of one line, and so we have this relation: If through the apparent position of the small star we draw a parallel to the projected minor axis, the ratio of the part of the projected semi-major axis cut off by this parallel, to the whole, reckoning distances from the centre, will be the cosine of the eccentric anomaly. Hence follows at once the construction for the position of the small star when the eccentric anomaly u is given.

Describe a circle on the projected major axis as diameter. Lay off on it two points C_1 and G_1 (Fig. 2) such that the angles C_0OC_1 and C_0OG_1 are equal to u, C_0 being the periastron. Join C_1G_1 and through its intersection D with OC_0 draw a parallel to the projected minor axis AB. The intersections S_1 and T_1 of this line with the apparent orbit will be the places of the star for the value u of the eccentric anomaly: for C_1G_1 is perpendicular to OC_0 and therefore $OD = OC_0 \cos u$. The coördinates of S_1 and T_1 may be read

off from the figure. In Fig. 2 the positions of the small star are shown for intervals of ⅛ of the period.

It is interesting to note that in the calculation of the ephemeris by this process, we do not need to know the position of the plane of the orbit, nor of the orbit in its plane, but only the period, periastron passage, and eccentricity. These may all be determined directly from the apparent orbit. So we can construct the ephemeris by this method quite independently of the construction for the elements of the orbit.

Fig. 2.



The construction shown in Fig. 2 may also be used to determine the period and periastron passage if a planimeter cannot conveniently be obtained. We need only know the apparent orbit and the star's places in it at two times as far apart as possible. Let these places be S_1 and S_2 and the corresponding times t_1 and t_2. By reversing the construction previously given we can find C_1 and C_2, and then the eccentric anomalies u_1 (C_0OC_1) and u_2 (C_0OC_2) of the star at the times of observation. From these we may derive the mean anomalies M_1 and M_2 by Kepler's equation $M = u - e \sin u$ since e is known from the apparent orbit. But from the definition of the mean anomaly, we have, if the period is P and the time of periastron passage T, the proportions

$P : t_2 - t_1 :: 360 : M_2 - M_1$ and $t_1 - T : t_2 - t_1 :: M_1 : M_2 - M_1$, which determine P and T.

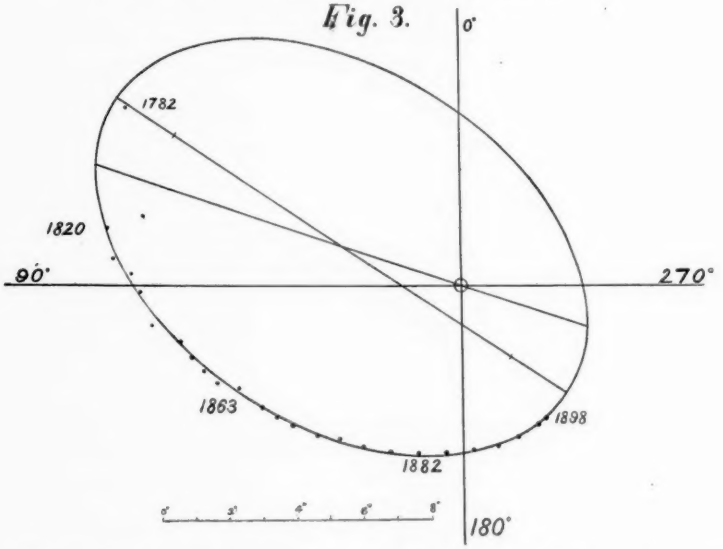
As a practical example of this method, I have computed the orbit of the well-known binary η Cassiopeæ. The observed angles and distances were plotted against the times of observation, and smooth curves drawn to represent the observations as nearly as possible. Normal places at intervals of five years were determined from these curves, and plotted on a large scale, and an ellipse drawn through them as nearly as possible, taking care not to violate the law of areas. After several trials the following apparent ellipse was found to be satisfactory.

Major axis.....16″.02	Minor axis.....10″.64
Angle of major axis.....57°.0	Angle of periastron.....252°.1

Star from centre.....3″.74

This orbit, with the observed places, is shown in Fig. 3, and is also used as the apparent orbit in Figures 1 and 2.

Fig. 3.



By the method above described I derive the following elements of the true orbit:

ELEMENTS.

$a = 8''.25$	$\lambda = 211°.2$
$e = 0.486$	$P = 202.5$ yrs.
$\Omega = 48°.8$	$T = 1908.1$
$i = 43\ .9$	$n = 1°.777$

Some of the orbits which have previously been computed for this star are:

P	T	e	a	Ω	i	λ	Authority	Source.
			″	°	°	°		
195.76	1907.84	0.5142	8.2128	46.1	45.95	217.87	See 1896	Bv. St. Syst. p. 75
190.50	1906.12	0.547	8.2047	43.0	46.08	222.02	See 1895	Astron. Jour. 343
208.1	1908.9	0.500	8.45	47.1	47.6	214.2	Lewis '94	Month. Not. LV. 20
167.4	1904.0	0.622	8.702	41.0	52.09	233.1	Coit 1882	" " XLII. 359
195.235	1901.95	0.6244	8.639	33.3	48.3	229.45	Gruber '76	Ast. Nach. 2111
222.435	1909.24	0.5763	9.83	39.9	53.83	223.33	Doberck '76	" " 2091

As less than half the apparent orbit has been described since the earliest observations, the elements, and especially the period, are still somewhat uncertain, and the differences of the results obtained by different computers, using different methods, are not at all surprising.

The orbit here found is similar to those recently found, especially to Lewis's. It represents the observations used well. The agreement of observed (mean of 3 yrs. measures) and computed places is satisfactory, the mean numerical value of the residuals being 0°.5 in angle, and 0″.07 in distance, and the greatest 1°.2 and 0″.22.

Two evidently erroneous early measures are excluded from this statement.

A short ephemeris follows:

1899.0.....216°.2.....4″.68	1903.0.....231°.0.....4″.45
1900.0.....219 .6.....4 .63	1904.0.....235 .0.....4 .37
1901.0.....223 .2.....4 .58	1905.0.....239 .1.....4 .28
1902.0.....227 .1.....4 .52	1906.0.....243 .4.....4 .20

March 19, 1898,

UNIVERSITY, Princeton, N. J.

NOTE.—Since the above article was prepared, I have discovered that Mr. H. J. Zwiers of Leiden has anticipated the methods I have used, in so far as regards the projection of the circumscribing circle of the true orbit in the determination of the elements. I make no claim to priority, but merely to independence of discovery. H. N. R.

THE VARIABLE STAR 7792 SS CYGNI.

J. A. PARKHURST.

FOR POPULAR ASTRONOMY.

Unusual interest has attached to this variable since its announcement in Harvard College Observatory Circular No. 12, on account of its short period and the character of its variation. It was discovered on the Harvard photographs by Miss Louisa D. Wells and the above mentioned circular stated its range of variation to be from 7.2 to less than 11.2 (photographic) magnitude, with a period of about 40 days. Neither the range of variation nor the period assigned, have been exactly confirmed by visual observations, but the star's changes are evidently somewhat irregular, and the details of the photographic measures have not yet been published, so that the materials at hand are not sufficient as a basis for an opinion as to the cause of the non-agreement of the two methods.

As soon as the Harvard circular, dated Nov. 2, 1896, was published, several observers began watching the star, and its variation was found to resemble that of U Geminorum, till then the only known example of the type, remaining at minimum magnitude for about three-fourths of its period, rising to maximum in a day or two, and falling more slowly to minimum. It seemed a matter of greatest importance to determine as accurately as possible the time of the sudden rise at each maximum, and as no one observer could be sure of seeing it in this uncertain climate, the writer sought the co-operation of other observers. Mr. Wm. E. Sperra, of Randolph, Ohio, began watching it 1897 Jan. 30, and Mr. Zaccheus Daniel, of Hawthorn, Pa., began June 30. The effort of each, with the writer, was to observe the star every clear night, in order to determine its behavior throughout the period. The two gentlemen mentioned promptly communicated their results, of which preliminary reports were published from time to time in POPULAR ASTRONOMY. The three series agreed so well that it was thought worth while to reduce them afresh, with the same light scale, therefore Messrs. Daniel and Sperra kindly sent me copies of their separate comparisons, and these, combined with my own observations form the basis of this paper. The instruments used were:

Daniel,	4-inch refractor,
Parkhurst,	6-inch reflector,
Sperra,	3-inch refractor.

It would not be expected that the results of three observers,

with such different instruments, would be sufficiently comparable to be treated as a single series, but the following comparison seems to furnish an adequate reason for so doing. On 87 dates the star was compared at nearly the same time by two or three observers. In each of these cases the mean of the two or three results was formed, and the differences taken between it and the individual magnitudes. In this comparison no observation was rejected, however poor the seeing, or however rapidly the variable was changing at the time. Nevertheless, the average value of the differences, without regard to sign, was only

Daniel,	$0^m.056$
Parkhurst,	0 .044
Sperra,	0 .051

As will be shown farther on, these differences are still smaller when the doubtful observations are excluded. This is the excuse for combining the results of the three observers into a single series.

Comparison Stars. Professor E. C. Pickering kindly sent me his photometric magnitudes of 14 of the comparison stars, and Mr. H. M. Parkhurst photometric magnitudes of 7, though with only preliminary results. There are two of the stars in Deichmüller's Astronomische Gesellschaft Catalogue. The magnitgdes of the stars common to the first two sources, with the initials of the authority, and my notation, are:

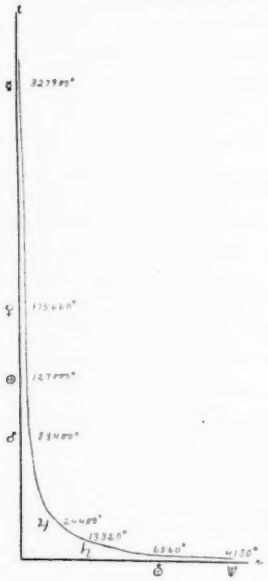
	DM. °	ECP. m	HMP. m	D. m
a	+ 42,4186	9.62	9.58	
c	+ 43,4020	9.39	9.62	
b	+ 42,4190	8.50	8.55	8.5
	+ 43,4030	8.90	9.05	
l	+ 42,4195	8.00	7.95	7.7
	+ 43,4037	8.60	8.74	

Of the 15 comparison stars which I used, the magnitudes of 8 were measured at Harvard, 5 by Mr. H. M. Parkhurst, and 2 estimated by Professor Deichmüller. Forming the mean of their results, giving weight 2 to the two former and 1 to the last, the light curve was platted with magnitudes as abscissæ and my step values from 350 comparisons, as ordinates. The points fell very close to a smooth curve, nearly a straight line, the greatest divergence being $0^m.13$ for *z*, a star used only a few times and whose magnitude depended on only one authority; and the average divergence being $0^m.03$, showing that my system is in good accord with the photometric measures. The above curve places the limit of visibility at $13^m.70$ on the photometric scale. To reduce to the scale I have been using a similar curve was drawn,

coinciding with the former at $8^m.0$ and reaching zero of the light scale at $12^m.80$. The stars were then entered on this curve with my step values, giving the following scale, to which Professor Pickering's magnitudes are appended for comparison.

COMPARISON STARS FOR 7792 SS CYGNI.

R. A. $21^h\ 38^m\ 46^s.2$, Decl. $+\ 43°\ 7'\ 35''$, (1900).



	Co-or. from V. R. A.	Decl.	Mag. P.	ECP.
	s			
$k+$	1	− 0.9	12.4	
$h-$	8.0	− 1.1	11.81	
$o+$	3.8	+ 5.4	11.58	12.14
$q-$	5 1	− 5.3	11.44	
$g-$	30.7	− 2.4	11.41	
$m-$	5.9	+ 4.2	11.30	11.77
$e-$	34.8	− 0.7	10.86	
$d-$	14.5	− 1.4	10.55	10.92
$p+$	19.5	+ 6.4	10.54	10.90
$n-$	7.6	+ 7.7	10.51	
$a-$	21.3	− 1.0	9.43	9.62
$c+$	0 3	+ 8.0	9.27	9.39
$z-$	55±	+ 27±	9.07	
$b+$	27.0	− 0.2	8.46	8.50
$l+$	123	− 8.7	7.92	8.00
$f+$	60±	+ 28±	(8.91)	*S*

The last star on the list was only used by Mr. Sperra, and the magnitude estimate is his.

Following are the reductions to the photometric scale:

Mag. P.	Red. to Phot. Scale. m
8.0	+ 0.00
9.0	+ 0.13
10.0	+ 0.28
11.0	+ 0.45
12.0	+ 0.66

The accompanying charts, reproduced from POPULAR ASTRONOMY Vol. IV, page 446 and V, page 272, shows the position of the nearer comparison stars.

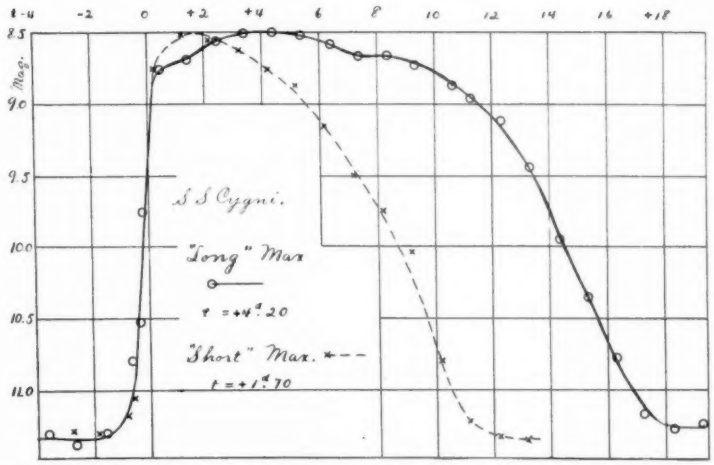
REDUCTIONS OF OBSERVATIONS TO A UNIFORM SYSTEM.

The agreement between the three series was improved by the following corrections. There were 26 cases of nearly simultaneous comparisons by all three observers, in good seeing, when the variable was not changing too rapidly. Forming the mean and taking the residuals of the separate observations, with regard to sign, the average values were:

	m
Daniel,	+ 0.022
Parkhurst,	+ 0.007
Sperra,	− 0.026

The smaller value in my case shows the effect of reducing all the observations with my light scale. The following corrections were therefore applied to the observed magnitudes of the three series:

	m
Daniel,	− 0.02
Parkhurst,	− 0.01
Sperra,	+ 0.03



With these corrections applied the 26 simultaneous observations give the residuals with regard to sign:

	m
Daniel,	+ 0.009
Parkhurst,	− 0 006
Sperra,	− 0.004

showing that the reduction to the same system is practically complete. All the good simultaneous observations by two or three observers, give for the average residuals, without regard to sign

	m	
Daniel,	0.041	65 obs.
Parkhurst,	0.040	62 "
Sperra,	0.036	35 "

The accompanying table gives in the first column the Julian day of observations, with decimal in Greenwich Mean Time, in the second column the magnitude as corrected by the quantities given above, followed by a colon if the seeing was poor or the

value depended on a single comparison, in the third column the initial of the observer.

7792 SS Cygni—Corrected Magnitudes, Correction to Z. Daniel, — 0^m.02, to J. A. Parkhurst — 0^m.01, to W. E. Sperra + 0^m.03.

J. D.	M.		J. D.	M.		J. D.	M.	
2413914.50	11.21	P	89.62	8.62	P	39.71	11.34	D
17.50	11.24	P	89.62	8.76	S	40.59	11.36	P
26.50	10.84:	P	94.67	9.86	D	41.63	11.25:	P
31.50	11.24	P	95.60	10.47	S	42.62	11.24:	P
33.50	10.99	P	95.67	10.53	D	42.63	11.28:	D
34.50	10.71	P	97.67	11.11	P	42.66	11.31:	S
44.50	8.34	P	96.62	10.89	D	43.58	11.35	D
46.58	8.44:	P	96.67	10.69	D	43.58	11.24	P
47.54	8.52	P	4099.63	11.31	S	44.59	11.11:	P
51.54	8.94	P	4099.71	11.19	D	44.62	11.21	D
53.54	9.39	P	4101.66	11.04:	P	44.86	11.05:	S
54.50	9.75	P	1.71	11.19	D	45.59	8.72	P
55.53	9.82	S	3.62	11.31	S	45.63	8.66	S
55.54	10.29	P	3.71	11.11	D	45.66	8.86	D
56.52	10.54	S	7.62	11.29	S	4145.91	8.62	P
56.54	10.49	P	7.66	11.11	P	4146.58	8.56	P
58.54	10.77	P	9.61	11.34	S	4146.62	8.43:	D
68.50	10.37:	P	11.62	11.13	P	47.57	8.49:	S
69.54	10.87:	P	12.60	11.31	S	47.58	8.65	D
79.97	11.2 :	S	12.71	11.38:	D	47.58	8.49	P
82.95	11.2 :	S	14.62	11.24	P	48.58	8.61	S
83.96	11.3 :	S	18.62	11.11	P	48.60	8.58	P
90.93	11.3 :	S	19.60	11.06	P	48.62	8.68	D
3998.94	10.89:	S	22.60	11.17	P	49.57	8.75	S
4003.93	10.96	S	23.59	11.31	S	49.58	8.76	P
5.90	8.37	S	23.62	11.21	P	49.66	8.78	D
6.93	8.49	S	23.63	11.29	D	50.56	8.82	S
10.89	9.24	S	24.62	11.14	P	50.58	8.91	P
11.93	9.83	S	4125.62	11.36	P	50.66	8.89	D
13.88	10.54:	S	4126.60	11.34	S	51.58	9.10	D
14.92	10.95	S	27.60	11.25	P	51.58	9.19	P
15.91	11.27	S	27.63	11.31	S	52.58	9.62	S
17.90	11.29	S	28.64	11.32	P	52.62	9.38	D
19.93	11.22	S	28.83	11.38	D	53.56	9.75	D
27.91	10.98	S	29.62	11.25	P	54.56	10.04	D
39.86	8.86	S	29.63	11.43	D	55.58	10.82	S
40.84	8.74	S	30.60	11.32	P	55.62	10.78	D
41.89	8.82	S	30.61	11.34	S	56.56	11.24	D
42.90	9.04	S	30.63	11.26	D	56.58	11.19	P
43.85	9.13	S	31.63	11.43:	D	56.58	11.17:	S
47.89	10.80	S	32.60	11.35	P	57.58	11.32	P
50.88	11.22:	S	33.62	11.35	P	57.66	11.31	D
4052.84	11.31:	S	34.60	11.36	S	58.62	11.35	D
4067.65	11.29:	S	34.65	11.24	P	62.58	11.3 :	S
76.63	11.3	S	34.67	11.43	D	64.58	11.3 :	S
77.62	11.29:	S	35.59	11.35	P	64.62	11.29	P
77.63	11.38	D	35.59	11.34	S	65.62	11.3 :	S
73.62	11.12	P	35.67	11.35	D	66.58	11.24	P
75.62	11.12	P	36.59	11.36:	P	67.56	11.3 :	S
80.75	8.66	S	36.59	11.41	S	67.63	11.35:	D
81.85	8.40	S	36.63	11.35	D	68.58	11.35	D
83.65	8.56	P	37.58	11.35	S	70.56	11.3 :	S
85.77	8.51	S	37.67	11.28	D	70.67	11.35	D
86.63	8.62	S	38.59	11.36:	P	71.56	11.22	P
87.66	8.39	P	38.59	11.34:	S	71.62	11.3 :	S
88.62	8.68	S	38.63	11.28	D	72.55	11.3 :	S
88.66	8.62	P	39.58	11.0 :	S	72.56	11.22:	P

J. D.	M.		J. D.	M.		J. D.	M.	
73.55	11.3 :	S	98.64	8.52	D	39.58	11.28:	D
73.56	11.29:	P	98.94	8.44:	P	40.50	11.29	P
74.58	11.35:	D	99.53	8.51	P	42.51	11.3 :	S
75.56	11.29:	P	4199.68	8.51	D	42.70	11.43:	D
76.58	11.43:	D	4200.53	8.47	S	45.50	11.29	P
4176.58	11.29:	P	00.54	8.57	P	45.60	11.3 :	S
2414177.54	11.36:	P	00.69	8.47	D	45.63	11.43:	D
77.6	11.28:	D	1.52	8.52:	S	46.50	11.44	P
78.56	11.29:	P	1.54	8.52:	P	46.55	11.35:	D
79.54	11.3 :	S	1.77	8.51	D	47.58	11.28:	D
80.57	11.32	P	2.53	8.59	P	49.50	11.36	P
81.54	11.25	P	2.60	8.57	D	49.60	11.3 :	S
81.75	11.28:	D	2.82	8.59	S	49.72	11.43	D
82.53	11.3 :	S	3.52	8.77:	P	52.54	11.36	P
82.54	11.32	P	3.53	8.62	D	53.65	11.28:	D
82.67	11.28	D	4.53	8.69	P	56.71	11.35	D
83.54	11.35	D	4.58	8.63	D	57.63	11.28:	D
83.54	11.29	P	5.53	8.76	P	59.50	9.22:	D
84.54	11.43	P	5.56	8.70	D	66.52	9.39	S
84.63	11.28:	D	6.52	8.84	P	67.49	9.87	S
85.56	11.3 :	S	6.60	8.77	D	68.47	9.90:	D
85.58	11.32	P	7.52	9.00	S	69.54	10.53:	D
85.63	11.43	D	7.53	8.96	P	74.59	11.3 :	S
86.54	11.36	P	7.56	8.93	D	75.52	11.28:	D
86.60	11.3 :	S	8.58	9.11:	D	2414275.58	11.3 :	S
86.71	11.48	D	9.57	9.36	P	2414283.51	11.3 :	S
87.53	11.3 :	S	9.65	9.51	D	87.56	11.28:	D
87.58	11.36	P	10.51	10.04	D	88.50	11.36	P
88.54	11.39	P	10.52	9.83:	P	93.50	11.3 :	S
88.60	11.3 :	S	10.54	9.93	S	4295.50	11.29:	S
88.67	11.48	D	11.52	10.10:	P	98.48	11.28:	D
89.54	11.43:	D	11.53	10.42	S	4298.51	11.3 :	S
89.54	11.39	P	11.55	10.46:	D	4306.50	10.94	P
89.60	11.3 :	S	12.50	10.81	S	6.50	11.3 :	S
90.54	11.29	P	12.51	10.54	P	7.50	8.63	D
91.54	11.36	P	12.54	10.95	D	7.52	8.77	P
92.58	11.29	P	13.50	11.12	S	8.50	8.71	D
92.60	11.3 :	S	13.53	11.24	D	8.52	8.71	P
92.63	11.35:	D	14.54	11.28:	D	8.52	8.69	S
93.54	11.29	P	15.50	11.28:	D	9.00	8.64:	P
93.58	11.48	D	2414215.54	11.21	P	10.50	8.52	P
94.53	11.3 :	S	2414216.58	11.28:	D	13.50	8.83	P
94.54	11.37	D	20.65	11.28:	D	14.52	8.71	D
94.54	11.29	P	21.54	11.39	P	14.55	8.74	S
94.88	11.24	D	21.59	11.3 :	S	16.50	8.80	P
95.54	10.85	D	21.67	11.28:	D	17.54	8.87	P
95.56	10.84	S	23.63	11.28:	D	19.51	8.89:	D
95.59	10.70	P	24.63	11.28:	D	19.52	8.87	P
95.85	10.54	S	25.58	11.28:	D	21.50	9.42	P
95.95	9.76	P	26.50	11.28:	D	22.55	9.83:	D
96.53	8.75	P	27.54	11.29	P	23.50	11.39:	D
96.50	8.78	D	28.54	11.36	P	23.50	10.27	P
96.55	8.68	S	28.70	11.28:	D	23.96	10.62	D
2414196.79	8.73	D	31.54	11.29	P	23.97	10.84	S
2414197.56	8.68	S	32.50	11.36	P	24.52	10.82	P
97.58	8.67	P	32.53	11.28:	D	24.97	11.28:	D
97.64	8.62	D	33.60	11.28:	D	26.52	11.44:	P
97.84	8.74	S	35.50	11.29	P	35.54	11.28:	D
98.52	8.52	P	35.59	11.28:	D	36.54	11.54	P
98.53	8.74	S	38.60	11.28:	D	2414349.93	11.28	D

This table contains 351 observations, the result of 688 separate comparisons, on 213 different dates between 1896 Dec. 20 and

1898 Feb. 28. They are divided between the three observers as follows:

	Observations.	Comparisons.	Diff. dates.
Daniel	114	190	111
Parkhurst	130	346	129
Sperra	107	152	110
	351	688	350

Results. When the above observations were platted the main characteristics of the star's variation appeared.

(1). It remains quiet at normal magnitude, 11.3, during two-thirds to three-fourths of the period.

(2). The rise begins suddenly, and attains a maximum velocity of 0.08 to 0.10 mag. per hour, the star reaching $9^m.0$ about 24 hours after the rise began.

(3). From this point it is necessary to distinguish sharply between the two types of maxima (similar to those of U Geminorum) which may be called the "long" and the "short," and which are clearly shown by the observations. The two types agree in a maximum magnitude of 8.5, but in the "long" type the star remains above normal 19 or 20 days, in the "short" type 11 to 13 days. Other difference in detail will follow.

Some definite time in the sudden rise will evidently furnish a better point for reckoning periods than the maximum itself. Acting on a suggestion by Mr. H. M. Parkhurst, I have chosen as this point, the time of passing $9^m.35$, the mean of the magnitudes of the conveniently placed comparison stars, *a* and *c*. Letting T_0 = the time of passing this magnitude, T = the time of observation, and t = the interval $T - T_0$, we have the following light curve for a typical "short" maximum, that of J. D. 241 4147.10 (1897 Aug. 10.10) from 40 observations, united in daily means, except for $t = -0.54$, where the change is so rapid that the observation must stand by itself.

Light Curve for the "Short" Maximum, 4147.10.

t	*M*	*t*	*M*	*t*	*M*
− 2.76	11.28	+ 2.18	8.56	+ 8.16	9.75
− 1.82	11.30	+ 3.20	8.62	+ 9.16	10.04
− 0.79	11.18	+ 4.20	8.76	+ 10.20	10.80
− 0.54	11.05	+ 5.20	8.87	+ 11.19	11.21
+ 0.23	8.75	+ 6.18	9.15	+ 12.22	11.32
+ 1.20	8.52	+ 7.20	9.50	+ 13.22	11.35

The most completely observed "long" maximum was that of 4200.40, and I accordingly give the light curve for comparison with the above. It is formed from the daily means of 65 observations, except where $t = -0.35$ and -0.25, which stand by themselves on account of the rapid change.

LIGHT CURVE FOR THE "LONG" MAXIMUM, 4200.40.

t	*M*	*t*	*M*	*t*	*M*
− 3.60	11.30	+ 3.41	8.51	+ 12.38	9.11
− 2.64	11.39	+ 4.39	8.50	+ 13.41	9.44
− 1.56	11.30	+ 5.41	8.52	+ 14.32	9.95
− 0.64	10.80	+ 6.45	8.58	+ 15.33	10.35
− 0.35	10.54	+ 7.33	8.67	+ 16.32	10.77
− 0.25	9.76	+ 8.36	8.66	+ 17.32	11.18
+ 0.44	8.74	+ 9.35	8.73	+ 18.34	11.28
+ 1.46	8.68	+ 10.36	8.81	+ 19.32	11.23
+ 2.41	8.57	+ 11.34	8.96		

A comparison of these curves by the aid of the graphic representation accompanying, shows that the rate of rise is about the same, if any different it is more rapid in the "short" maximum, but after passing 8.9 magnitude the curves diverge sharply, that for the "short" maximum rising to a well defined phase at $t = +1.70$, and falling to normal at $t = +11.5$. The curve for the "long" maximum, on the contrary, after passing 8.9 magnitude is checked in the rise and does not reach maximum till $t = +4.20$. After the fall begins there is a standstill at about 8.7 magnitude from $t = 7.0$ to 8.5. In other maxima of this type this amounts to a secondary maximum, 8.7 magnitude, at $t = 8.4$. After this the fall is steady and about as rapid as in the corresponding part of the curve for "short" maximum, the normal light being reached at $t = +18.0$.

The degree of correspondence between these specimen curves and the other observed maxima, may be judged by the following table.

RESULTS FOR MAXIMA.

No.	1	2	3	4	5	6	7	8
Maximum	241 3945 1897	4006	4040	4084.6	4147.10	4200.40	4261 1897	4311.4 1898
"	Jan. 20	Mar. 22	Apr. 25	June 8.6	Aug. 10.10	Oct. 1.40	Dec. 2	Jan 21.4
Magnitude	8.4±	8.5±	8.7	8.5	8.50	8.50	?	8.5
Interval	61	34	44	62.5	53.3	61	50	
Rise begun	3939?	4003	4038?	4079?	4144	4194	4258	5306
Passed 11 mag.	3940?	4004.0	4038.5?	4079.8?	4144.8	4195.4	4259.0?	4306.5
" 10 mag.		4004.2			4145.20	4196.0		4306.9
" 9.35 M.		4004.5	4039.0?	4080.4	4145.40	4196.20	4259.5	4307.2
Interval		34.5	41.4	65.0		50.8	63.3	47.7
Falling								
Passed 9m.35	3952.4	4011.2	4044.6—	4093.6±	4152.20	4209.3	4260.5	4321.0
Passed 11.0	3958—	4015.0	4048.2	4097.0	4156.0	4213.1	4270.3?	4324.6
Reached normal mag.	3959—	4015.9	4049.0—	4098.0±	4157.0	4214.1	4271.5?	4325.4
Remained above normal	20±	13±	11±	19	13	20	13	19
Above 11.0 M.	18?	11.0	10?	17.2?	11.2	17.7	11±	18.1

In the above table of results for maxima, the dates followed by a ? were estimated by the aid of the curves for the more completely observed maxima, those followed by a — were obtained from the individual curves but are more or less uncertain on account of an insufficient number of observations.

Normal Periods. It was a matter of considerable interest to determine whether the star remained at a constant magnitude during its period of normal light. The magnitudes observed during these periods were therefore grouped in five-day means, and as there was an indication that the light became fainter during the latter part of the period, the mean of the first half was compared with that of the latter half. These details, with some others, are given in the following table.

RESULTS FOR NORMAL PERIODS.

Between Maxima.	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Remained normal	44 ± 2	22?	30 ± 2	46	37	44 ± 1	34 ± 2
From 5 day means { Mean mag.				11.26	11.32	11.31	
From 5 day means { Brightest				11.20	11.28	11.25	
From 5 day means { Faintest				11.34	11.37	11.36	
Mean 1st half of period				11.22	11.31	11.29	
Mean 2nd half of period				11.31	11.33	11.33	
From single observations { Brightest	10.37:	10.98	11.12	11.11	11.22	11.21	11.28
From single observations { Faintest	11.3:	11.29	11.31:	11.43	11.48	11.44	11.36
No. of observations	8	4	7	57	58	37	10

From the two tables given above the following conclusions may be drawn:

(1) Counting from the time of passing $9^m.35$ on the rise (the first maximum must be excluded as insufficiently observed) the mean of the 6 intervals is 50.5 days, the greatest interval being 65.0 and the least 34.5 days. The corresponding intervals, counting from the maxima are, mean 50.8, greatest 63, least 34. Including the first maximum, the mean interval is 52.4, days.

(2) The mean duration of the period of normal light is 37 days the greatest 46, the least 22.

(3) The star remains practically constant in light during the normal period, the average difference between the magnitudes of the first and second halves, 0.05, being too slight to furnish reliable evidence of a progressive fall.

(4) The magnitude for all the well observed maxima is 8.5, for the normal periods 11.3.

(5) In the effort to predict coming maxima it was suggested to me by Mr. Daniel that the time taken by the fall from maximum to normal was proportional to the following normal period. If we examine the foregoing tables we find that every "long" maximum is followed by a normal period of 44 to 46 days, while every "short" maximum is followed by a normal period of average length (37 days) or shorter. This conclusion is strengthened by the maximum which has been passed during the preparation

of this paper. It was a "short" one, the rise beginning 4369, the maximum being passed at 4371.6 and the normal reached 4382, giving the duration of normal light 44 days. This can by no means be considered as an established law of variation but seems to be the best deduction possible with the present data.

EPHEMERIDES OF SATELLITES.*

J. MORRISON, M. A., M. D., PH. D.

FOR POPULAR ASTRONOMY.

When a satellite is carefully observed during an entire revolution, it is found to describe a curve which does not sensibly differ from an ellipse, or to move to and fro in a straight line passing through the centre of the planet. This latter motion can only take place when the Earth is situated in the plane of the satellite's orbit or is passing the node on the ecliptic. With the exception of the three outermost satellites of Saturn, viz.: Iapetus, Hyperion and Titan, the actual orbits of all the other known satellites are regarded as circles. Owing however to the disturbance of other bodies in the solar system, the orbits must approach more nearly to an ellipse than to a circle, but the eccentricity is so exceedingly small that it can be practically disregarded without any appreciable error whatever. The orbits of the three satellites just named are, however, decidedly elliptical with tolerably large eccentricities and must be treated accordingly.

The apparent orbit or that which is actually observed, is the projection of the real orbit on a plane perpendicular to the line of vision and passing through the centre of the planet. When the real orbit is a circle, the apparent orbit is an ellipse with the planet in the centre, and when the real orbit is an ellipse, the apparent one will also be an ellipse but the planet will be in neither the centre nor the focus.

TO DETERMINE THE POSITION OF A SATELLITE IN ITS APPARENT ORBIT AT ANY TIME WHEN THE ELEMENTS OF ITS REAL ORBIT ARE KNOWN.

Let α, δ, Δ be the geocentric polar coördinates of the planet,
α', δ', Δ' the geocentric polar coördinates of the satellite,
and a, d, r the planetocentric polar coördinates of the satellite,
referred to the equator and equinox of the epoch for which the ephemeris is to be computed.

* Extracted in part from the author's paper in the Monthly Notices of the Royal Astronomical Society of England, Vol. 44, No. 8, June, 1884.

The general expressions for the rectangular coördinates in terms of the polar are

$$\begin{aligned} x &= \Delta \cos \delta \cos \alpha \\ y &= \Delta \cos \delta \sin \alpha \\ z &= \Delta \sin \delta \end{aligned}$$

Therefore by equating the rectangular coördinates of the bodies we have

$$\begin{aligned} \Delta' \cos \delta' \cos \alpha' &= \Delta \cos \delta \cos \alpha + r \cos d \cos a \\ \Delta' \cos \delta' \sin \alpha' &= \Delta \cos \delta \sin \alpha + r \cos d \sin a \\ \Delta' \sin \delta' &= \Delta \sin \delta + r \sin d \end{aligned} \quad (203)$$

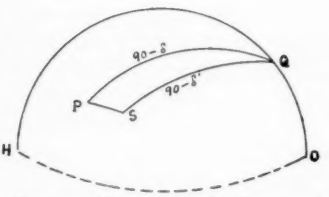
Multiplying the first of this group by $\cos \alpha$, the second by $\sin \alpha$ and adding the results, and again multiplying the first by $\sin \alpha$, the second by $\cos \alpha$ and subtracting we have

$$\begin{aligned} \Delta' \cos \delta' \cos (\alpha' - \alpha) &= \Delta \cos \delta + r \cos d \cos (a - \alpha) \\ \Delta' \cos \delta' \sin (\alpha' - \alpha) &= r \cos d \sin (a - \alpha) \\ \Delta' \sin \delta' &= \Delta \sin \delta + r \sin d \end{aligned} \quad (204)$$

We have now to consider the spherical triangle formed by the north pole of the equator, the planet and the satellite; thus let Q be the north pole, P the planet and S the satellite, then in the spherical triangle PQS we have $PQ = 90° - \delta$, $QS = 90° - \delta'$ and $PQS = \alpha' - \alpha$

Put $PS = s$, the apparent distance of the satellite from the planet as seen from the Earth

and $QPS = p$, the angle of position of the satellite reckoned from the north toward the east and from 0° to 360°.



By the fundamental formulæ of spherical trigonometry we have

$$\begin{aligned} \sin s \sin p &= \cos \delta' \sin (\alpha' - \alpha) \\ \sin s \cos p &= \cos \delta \sin \delta' - \sin \delta \cos \delta' \cos (\alpha' - \alpha) \\ \cos s &= \sin \delta \sin \delta' + \cos \delta \cos \delta' \cos (\alpha' - \alpha) \end{aligned} \quad (205)$$

Multiplying by Δ' and substituting from (204) this group becomes

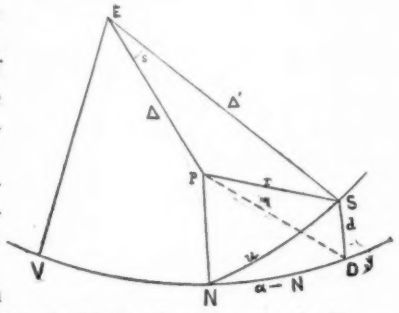
$$\begin{aligned} \Delta' \sin s \sin p &= r \cos d \sin (a - \alpha) \\ \Delta' \sin s \cos p &= r [\cos \delta \sin d - \sin \delta \cos d \cos (a - \alpha)] \\ \Delta' \cos s &= \Delta + r [\sin \delta \sin d + \cos \delta \cos d \cos (a - \alpha)] \end{aligned} \quad (206)$$

from which we must eliminate a, d and Δ'.

Let VD represent an arc of the equator, NS an arc of the orbit

of the satellite, E the Earth, P the planet and S the satellite; draw SD perpendicular to VD and let EV be the direction of the vernal equinox. Then N will be the position of the ascending node of the orbit of the satellite on the equator; VD and SD the planetocentric right ascension and declination of the satellite which we have denoted by a and d respectively.

Put $VN = N$, the R. A. of the ascending node;
$SND = i$, the inclination of the orbit to the plane of the equator;
$NS = u$, the angular distance of the satellite from the ascending node;
then $ND = a - N$, and from the right angled spherical triangle NSD whose center is P, we have



$$\begin{aligned} \cos d \cos (a - N) &= \cos u \\ \cos d \sin (a - N) &= \sin u \cos i \\ \sin d &= \sin u \sin i \end{aligned} \qquad (207)$$

Multiplying the first of this group by $\cos (\alpha - N)$, the second by $\sin (\alpha - N)$ and adding the results; also multiplying the first by $\sin (\alpha - N)$ and the second by $\cos (\alpha - N)$ and subtracting we have

$$\begin{aligned} \cos d \cos (a - \alpha) &= \sin u \cos i \sin (\alpha - N) + \cos u \cos (\alpha - N) \\ \cos d \sin (a - \alpha) &= \sin u \cos i \cos (\alpha - N) - \cos u \sin (\alpha - N) \\ \sin d &= \sin u \sin i \end{aligned}$$

and substituting these in (206) we have after some simple reductions

$$\begin{aligned} \Delta' \sin s \sin p &= r \sin u \cos i \cos (\alpha - N) - r \cos u \sin (\alpha - N) \\ \Delta' \sin s \cos p &= r \sin u \,(\cos \delta \sin i - \sin \delta \cos i \sin (\alpha - N)) \\ &\quad - r \sin \delta \cos u \cos (\alpha - N) \qquad (208) \\ \Delta' \cos s &= \Delta + r \sin u \,(\sin \delta \sin i + \cos \delta \cos i \sin (\alpha - N)) \\ &\quad + r \cos \delta \cos u \cos (\alpha - N) \end{aligned}$$

from which Δ' must be eliminated.

In the plane triangle EPS formed by joining the Earth, planet and satellite, let σ denote the supplement of the angle EPS, then we shall evidently have

$$\begin{aligned} \Delta' \sin s &= r \sin \sigma \\ \Delta' \cos s &= r \cos \sigma + \Delta \end{aligned} \qquad (209)$$

which being substituted in (208) give after reduction

$$\begin{aligned}
\sin\sigma\sin p &= \sin u\cos i\cos(\alpha-N)-\cos u\sin(\alpha-N)\\
\sin\sigma\cos p &= \sin u\,(\cos\delta\sin i-\sin\delta\cos i\sin(\alpha-N))\\
&\qquad -\cos u\sin\delta\cos(\alpha-N) \qquad (210)\\
\cos\sigma &= \sin u\,(\sin\delta\sin i+\cos\delta\cos i\sin(\alpha-N))\\
&\qquad +\cos u\cos\delta\cos(\alpha-N)
\end{aligned}$$

These equations are perfectly rigorous and determine σ and p without ambiguity, but as the angle σ can not be compared directly with observation, it will be more convenient to express σ in terms of s which can be observed; thus from (209) we have

$$\tan s = \frac{r\sin\sigma}{r\cos\sigma+\Delta} \qquad (211)$$

and since s is always very small, we may substitute the arc for the tangent and develop the second member into a series.

Hence we have

$$s = \frac{r}{\Delta}\sin\sigma-\frac{1}{2}\frac{r^2}{\Delta^2}\sin 2\sigma+\frac{1}{3}\frac{r^3}{\Delta^3}\sin 3\sigma-\text{etc.} \qquad (212)$$

Now r is always very small compared with Δ, and therefore the terms containing the square and higher powers of $\frac{r}{\Delta}$ may be neglected without sensibly affecting the result.

We shall then have

$$s'' = \frac{r}{\Delta\sin 1''}\sin\sigma \qquad (213)$$

and if a'' be the value of $\frac{r}{\sin 1''}$ at distance unity, then $\frac{a''}{\Delta}$ will be its value at distance Δ, therefore the last equation may be written thus

$$s'' = \frac{a''}{\Delta}\sin\sigma \qquad \text{whence} \qquad \sin\sigma = \frac{\Delta}{a''}\cdot s'' \qquad (214)$$

which substituted in the first two equations of (210) gives

$$\begin{aligned}
s''\sin p &= \frac{a''}{\Delta}\{\sin u\cos i\cos(\alpha-N)\cos u\sin(\alpha-N)\}\\
s''\cos p &= \frac{a''}{\Delta}\{\sin u\,(\cos\delta\sin i-\sin\delta\cos i\sin(\alpha-N) \qquad (215)\\
&\qquad -\cos u\sin\delta\cos(\alpha-N)\}
\end{aligned}$$

The error committed in s'' by omitting the second term of (212)

is $$\frac{1}{2}\frac{r^2}{\Delta^2}\frac{\sin 2\sigma}{\sin 1''}$$

which is a maximum when $\sigma = 45°$ or $135°$.

Put $\frac{1}{2}\frac{r^2}{\Delta^2}\cdot\frac{1}{\sin 1''} = \eta$ then $\frac{r}{\Delta} = \sqrt{\eta \sin 2''}$, but $\frac{r}{\Delta}$ is the tangent of the angle of greatest elongation as seen from the earth, hence putting

$$\frac{r}{\Delta} = \tan \varepsilon \text{ we have } \eta = \frac{\tan^2 \varepsilon}{\sin 2''}$$

when		
	$\varepsilon = 0'\ 50''$	$\eta = 0''.006$
	$\varepsilon = 1\ \ 50$	$\eta = 0.\ \ 029$
	$\varepsilon = 3\ \ 35$	$\eta = 0.\ \ 112$
	$\varepsilon = 5\ \ 46$	$\eta = 0.\ \ 290$
	$\varepsilon = 9\ \ 45$	$\eta = 0.\ \ 829$

Thus we see, that for the satellites of Mars, Saturn, Uranus, Neptune and the three inner satellites of Jupiter whose greatest angle of elongation does not exceed 6′, the error committed in s'', is less than 0″.3 and for Callisto the fourth satellite of Jupiter whose elongation is never more than 9′ 45″, the error can never exceed 0″.83. The formulæ (213) may therefore be regarded as practically exact.

In order to adapt (210) and (215) to logarithmic computation put,

$$\begin{aligned} \sin f \cos F &= \cos i \cos (\alpha - N) \\ \sin f \sin F &= -\sin (\alpha - N) \\ \cos f &= -\sin i \cos (\alpha - N) \end{aligned} \tag{216}$$

$$\begin{aligned} \sin g \cos G &= \cos \delta \sin i - \sin \delta \cos i \sin (\alpha - N) \\ \sin g \sin G &= -\sin \delta \cos (\alpha - N) \\ \cos g &= \cos \delta \cos i + \sin \delta \sin i \sin (\alpha - N) \end{aligned} \tag{217}$$

$$\begin{aligned} \sin h \cos H &= \sin \delta \sin i + \cos \delta \cos i \sin (\alpha - N) \\ \sin h \sin H &= \cos \delta \cos (\alpha - N) \\ \cos h &= \sin \delta \cos i - \cos \delta \sin i \sin (\alpha - N) \end{aligned} \tag{218}$$

then (210) and (215) become

$$\begin{aligned} \sin \sigma \sin p &= \sin f \sin (F + u) \\ \sin \sigma \cos p &= \sin g \sin (G + u) \\ \cos \sigma &= \sin h \sin (H + u) \end{aligned} \tag{219}$$

and

$$\begin{aligned} s'' \sin p &= \frac{a''}{\Delta} \sin f \sin (F + u) \\ s'' \cos p &= \frac{a''}{\Delta} \sin g \sin (G + u) \end{aligned} \tag{220}$$

The last group which is known as Bessel's formulæ, gives s'' and

p for any given date and also enables us to compare the computed with the observed place. When s and p are required for a series of dates, it will be most convenient to compute the values of the auxiliary angles f, F, g and G for the mean noon of several consecutive days and then interpolate for any intermediate date.

The auxiliaries h and H will not be required unless we desire to check the value of σ in (219).

From the position angle and the apparent distance as found by observation we may compute the radius rector and the value of u or the distance of the satellite from the node and compare these with the values deduced from the elements of the orbit.

Resuming equations (220) and putting $r = \frac{a''}{\Delta}$, we have

$$s \sin p = r \sin f \sin (F + u)$$
$$s \cos p = r \sin g \sin (G + u)$$

from which to find r and u, s and p being known from observation and f, F, g and G from (216) and (217).

Multiply the first of these by $\sin g \sin G$ and the second by $\sin f \sin F$, subtract the second product from the first, factor and divide by $\sin f \sin g \sin (G - F)$ and we obtain

$$s\left(\frac{\sin G}{\sin f \sin (G-F)} \sin p - \frac{\sin F}{\sin g \sin (G-F)} \cos p\right) = r \sin u$$

Put $\frac{\sin G}{\sin f \sin (G-F)} = f' \cos F'$ and $\frac{\sin F}{\sin g \sin (G-F)} = f' \sin F'$

and the above becomes

$$s f' \sin (p - F') = r \sin u \qquad (221)$$

Similarly, by multiplying the first by $\sin g \cos G$ and the second by $\sin f \cos F$, subtracting etc. and putting

$$\frac{\cos G}{\sin f \sin (F-G)} = g' \cos G' \text{ and } \frac{\cos F}{\sin g \sin (F-G)} = g' \sin G'$$

we get

$$s g' \sin (p - G') = r \cos u \qquad (222)$$

whence

$$\tan u = \frac{f' \sin (p - F')}{g' \sin (p - G')}$$

and

$$r = \frac{s f' \sin (p - F')}{\sin u} = \frac{s g' \sin (p - G')}{\cos u} \qquad (223)$$

which determine u and r without ambiguity.

To Find the Time of Greatest Eastern or Western Elongation, the Position Angles and the Distance of the Satellite from the Planet.

Let us conceive three planes to be passed as follows:—

The *first* through the centre of the planet and the poles of the equator and orbit of the satellite; the *second* through the centre of the planet, the pole of the orbit of the satellite and the centre of the Earth; the *third* through the centre of the planet, the pole of the equator and the centre of the earth.

These three planes will determine on the celestial sphere a spherical triangle having its centre at the centre of the planet.

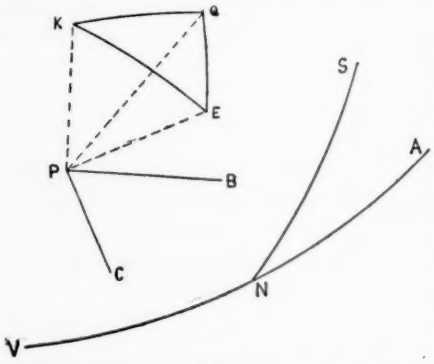
Let AV represent an arc of the equator, NS an arc of the orbit of the satellite, Q the pole of the equator, K the pole of the orbit of the satellité, N the position of the ascending node, P the planet and E the Earth. Join PE, PK and PQ, and in the plane KPE draw PB perpendicular to PK and PC perpendicular to PE; then PB will lie in the plane of the orbit and PC in the plane of the apparent orbit which is the projection of the former on the plane passing through P and perpendicular to the line PE joining the Earth and planet.

Put θ = the angle EPB.
q = the angle of position of the minor axis of the apparent orbit,
$p_0 = q - 90°$, the angle of position of the major axis,
u_0 = the angular distance of the end of the major axis from the ascending node measured on the orbit of the satellite,
a and b = the semi major and minor axes respectively of the apparent orbit;

then in the spherical triangle EKQ we shall have

$KQ = i$, the inclination of the orbit of the satellite,
$EQ = \delta + 90°$, the polar distance of the Earth as seen from the planet, and
EQK = the difference between the R. A. of the Earth and the R A. of the pole of the orbit of the satellite,
$= (\alpha - 180°) - (N - 90°)$
$\alpha - N - 90°$;

hence the remaining three parts of the triangle can be found.



Since the planes PKE and PKQ pass through the pole of the orbit, they are perpendicular to its plane and the former intersects the orbit in those points which, as seen from the Earth, are nearest to the planet, or in other words, the intersection of the plane PKE with the apparent orbit, determines the minor axis, while the plane PKQ being perpendicular to the planes of the equator and of the orbit of the satellite, intersects the latter at a point 90° distant from the node. The angle EKQ being the inclination of these two planes is measured by the arc of the orbit intercepted between these two points of intersection; now the side KQ will intersect the orbit in a point whose position is $90° + N$; and if we denote the position of the intersection of the side KE with the orbit by β, we shall have

$$\text{the angle } EKQ = 90° + N - \beta.$$

But since the plane PKE intersects the apparent orbit in its minor axis, the position at that point of the orbit at which the satellite, as seen from the Earth, will be at its greatest eastern elongation will be $\beta - 90°$, and therefore the distance of this point from the node will be

$$\beta - 90° - N$$

therefore we have $u_0 = \beta - 90° - N.$

But we have just shown that the

$$\text{angle } KEQ = -\beta + 90° + N$$
$$= -u_0.$$

The angle KEQ is the angle of position of the minor axis of the apparent orbit; hence we have

$$\text{angle } EKQ = q = p_0 - 90°.$$

The side KE is the angular distance of the Earth from the pole of the orbit, as seen from the planet and is equal to the angle BPC; therefore we have

$$KE = 90° - \theta,$$

where θ is always to be taken between $+ 90°$ and $- 90°$. When

θ is *positive* the Earth will be on the *north* side of the plane of the orbit and the position angle will *increase*, and where θ is *negative* the Earth will be on the *south* side and the position angle will *decrease*.

The fundamental formulæ of spherical trigonometry being applied to the triangle EKQ, we have

$$\begin{aligned}
\cos EK &= \cos KQ \cos EQ + \sin KQ \sin EQ \cos KQE \\
\sin EK \cos EKQ &= \sin KQ \cos EQ - \cos KQ \sin EQ \cos KQE \\
\sin EK \sin EKQ &= \sin EQ \sin KQE \\
\sin EK \cos KEQ &= \sin EQ \cos KQ - \cos EQ \sin KQ \cos KQE \\
\sin EK \sin KEQ &= \sin KQ \sin KQE
\end{aligned}$$

But we have shown that

$$KQ = i,\ EQ = \delta + 90^\circ \text{ and } KQE = \alpha - N - 90^\circ$$

which are known; and

$$EK = 90^\circ - \theta,\ EKQ = -u_0 \text{ and } KEQ = p_0 - 90^\circ$$

which are to be found.

Substituting these values of the sides and angles in the preceding formulæ, we have

$$\begin{aligned}
\sin\theta &= -\cos i \sin\delta + \sin i \cos\delta \sin(\alpha - N) \\
\cos\theta\cos u_0 &= -\sin i \sin\delta - \cos i \cos\delta \sin(\alpha - N) \\
\cos\theta \sin u_0 &= \cos\delta\cos(\alpha - N) \\
\cos\theta \sin p_0 &= \cos i\cos\delta + \sin i \sin\delta \sin(\alpha - N) \\
\cos\theta\cos p_0 &= \sin i \cos(\alpha - N)
\end{aligned} \tag{224}$$

for the determination of θ, u_0 and p_0. The agreement of the two values of $\cos\theta$ with the one value of $\sin\theta$ will serve to check the accuracy of the computation. It now remains to transform these equations for logarithmic calculation.

If we put

$$\begin{aligned}
c \sin C &= \cos i \\
c \cos C &= \sin i \sin(\alpha - N)
\end{aligned} \tag{225}$$

and

$$\begin{aligned}
c' \sin C' &= \sin i \\
c' \cos C' &= -\cos i \sin(\alpha - N)
\end{aligned}$$

and remembering that for the greatest western elongation $-u_0$ becomes $-u_0 + 180^\circ$ and p_0 becomes $p_0 + 180^\circ$, we shall have

$$\begin{aligned}
\sin\theta &= c\cos(C + \delta) \\
\cos\theta\cos u_0 &= \pm c'\cos(C' + \delta) \\
\cos\theta \sin u_0 &= \pm\cos\delta\cos(\alpha - N) \\
\cos\theta \sin p_0 &= \pm c \sin(C + \delta) \\
\cos\theta\cos p_0 &= \pm \sin i \cos(\alpha - N)
\end{aligned} \tag{226}$$

where the upper sign applies to the greatest eastern and the lower to the greatest western elongation. Now if u denote the distance of the satellite from the ascending node at the date T and if t denote the time of greatest elongation we shall have

$$(t - T)\ \mu = u_0 - u$$

whence
$$t = T + \frac{u_0 - u}{\mu} \qquad (227)$$

where μ is the daily (or hourly) motion in orbit. We also have

$$\begin{aligned} b'' &= a'' \cos KE \\ &= a'' \sin \theta \end{aligned} \qquad (228)$$

which determines the semi minor axis of the apparent orbit.

The British Nautical Almanac employs the following formulæ for determining q and θ, viz.:

$$\tan q = -\frac{\sin Q \cot (\alpha - N)}{\cos (Q - \delta)}$$

and
$$\tan \theta = \tan (Q - \delta) \cos q$$

where
$$\tan Q = \tan i \sin (\alpha - N)$$

of which the demonstration is as follows:—Resuming the first and last two equations of (224), remembering that $p_0 = q + 90°$, we have

$$\begin{aligned} \sin \theta &= -\cos i \sin \delta + \sin i \cos \delta \sin (\alpha - N) && (a) \\ \cos \theta \cos q &= \cos i \cos \delta + \sin i \sin \delta \sin (\alpha - N) && (b) \\ \cos \theta \sin q &= -\sin i \cos (\alpha - N) && (c) \end{aligned}$$

Dividing (c) by (b) and putting $\tan Q = \tan i \sin (\alpha - N)$ we get

$$\begin{aligned} \tan q &= -\frac{\sin i \cos (\alpha - N)}{\cos i \cos \delta + \sin i \sin \delta \sin (\alpha - N)} \\ &= -\frac{\tan i \cos (\alpha - N)}{\cos \delta + \sin \delta \tan Q} \\ &= -\frac{\tan i \cos (\alpha - N) \cos Q}{\cos (Q - \delta)}, \text{ but } \tan i = \frac{\tan Q}{\sin (\alpha - N)} \\ &= -\frac{\sin Q \cot (\alpha - N)}{\cos (Q - \delta)} \end{aligned} \qquad (229)$$

Again dividing (a) by (b) we have after reducing

$$\frac{\tan \theta}{\cos q} = \frac{-\sin \delta + \cos \delta \tan Q}{\cos \delta + \sin \delta \tan Q} = \tan (Q - \delta)$$

therefore
$$\tan \theta = \tan (Q - \delta) \cos q \qquad (230)$$

A check on these formulæ may be deduced thus:—

since $\tan Q = \tan i \sin (\alpha - N)$

we have
$$\sin i \sin (\alpha - N) = \frac{\cos i \sin Q}{\cos Q}$$

and dividing this by (b) we get

$$\frac{\sin i \sin (\alpha - N)}{\cos \theta \cos q} = \frac{\cos i \sin Q}{\cos Q(\cos i \cos \delta + \sin i \sin \delta \sin (\alpha - N))}$$

$$= \frac{\sin Q}{\cos Q(\cos \delta + \sin \delta \tan i \sin (\alpha - N))}$$

$$= \frac{\sin Q}{\cos Q(\cos \delta + \sin \delta \tan Q'}$$

$$= \frac{\sin Q}{\cos (Q - \delta)} \qquad (231)$$

an equation which involves all the known and unknown quantities and which will be satisfied only when they are all correct.

GEOCENTRIC CONJUNCTION.

At the instant of geocentric conjunction $p = 0$ or $180°$, $\sin p = 0$ and $\cos p = \pm 1$.

therefore the first of (220) gives

$$\sin (F + u) = 0$$

or $$F + u = 0 \text{ or } 180°$$

therefore $$u = -F \text{ or } u = 180° - F$$

and from (216) we get

$$\tan F = -\frac{\tan (\alpha - N)}{\cos i}$$

and therefore in both cases we have

$$\tan u = \frac{\tan (\alpha - N)}{\cos i} \qquad (232)$$

hence u and $(\alpha - N)$ will be in the same quadrant. This formulæ results also from the right spherical triangle whose base is $(\alpha - N)$ and one of its angles i.

From the second of (220) we have when $p = 0$

$$s = \frac{a}{\Delta} \sin g \sin (G + u)$$

$$= A \sin (G - F) \qquad \text{where} \qquad A = \frac{a}{\Delta} \sin g$$

and when $p = 180$

$$-s = A \sin (G + 180° - F) = -A \sin (G - F)$$

and therefore in both cases

$$s = A \sin (G - F) \qquad (233)$$

When the real orbit is an ellipse as in the case of Titan, Hyper-

ion and Iapetus, the values of r and u for any date, are obtained from the elements of the satellite's orbit thus:

u = mean anomaly + equation of the centre + distance from node to periplaneten

$$= M + E + \omega \qquad (234)$$

The values of r and E (the equation of the centre) are furnished by tables prepared for each satellite, or they may be computed from the following formulæ, for the demonstration of which see the author's paper in the Monthly Notices of the Royal Astronomical Society of England, Vol. 43, No. 7, May 1883.

$$\log \frac{r}{a} = \frac{e^2}{4} + \frac{e^4}{32} + \frac{e^6}{96} + \ldots$$
$$+ \left(-e + \frac{3}{8}e^3 + \frac{e^5}{64} + \ldots\ldots\right)\cos M$$
$$+ \left(-\frac{3}{4}e^2 + \frac{11}{24}e^4 + \frac{3}{64}e^6 + \ldots\right)\cos 2M$$
$$+ \left(-\frac{17}{24}e^3 + \frac{77}{128}e^5 + \ldots\ldots\right)\cos 3M$$
$$+ \left(-\frac{71}{96}e^4 + \frac{129}{160}e^6 + \ldots\ldots\right)\cos 4M$$
$$\ldots\ldots + \ldots\ldots\ldots\ldots$$

and

$$E = \left(2e - \frac{e^3}{4} + \frac{5}{96}e^5 + \ldots\ldots\right)\sin M$$
$$+ \left(\frac{5}{4}e^2 - \frac{11}{25}e^4 + \frac{17}{192}e^6 + \ldots\right)\sin 2M$$
$$+ \left(\frac{13}{12}e^3 - \frac{43}{64}e^5 + \ldots\ldots\right)\sin 3M$$
$$+ \left(\frac{103}{96}e^4 - \ldots\ldots\right)\sin 4M$$
$$+ \ldots\ldots\ldots$$

Where e is the eccentricity, M the mean anomaly and a the satellite's mean distance or the semi-axis major of its orbit.

The values of s and p and also of u_0 and p_0 can then be computed on the supposition of a circular orbit of radius r as above found.

Since the angular velocity in an elliptic orbit varies inversely at the square of the radius vector, if μ be the angular velocity (per minute or hour) at the mean distance a, then the angular velocity at distance r will be $\mu_1 = \frac{\mu}{r^2}$ which is to be used for μ in (227) in computing the correction to T. If u_0 differs considerably from u,

the value of t thus found will be only an approximation, and a recomputation for this approximate time will be necessary.

For the time of conjunction, u is determined by (232) which must also satisfy (234) subject to the condition that $p = 0°$ or $180°$ and the distance from the centre of the planet by (233).

It now remains to make an application of the preceding formulæ and for this purpose we will compute the apparent position and date of greatest elongation of Deimos for 1899 Jan'y 18*d* Greenwich M. T.

The elements of the orbit of Deimos corrected by the observations made at the Lick Observatory in 1888 and reduced to the equator and equinox of the above date are as follows:

EPOCH 1899 JAN'Y $18^d.0$ G. M. T.

Period	$30^h\ 17^m\ 9026$
μ	$285°.163634$
a	$32''.36$ (at distance 1)
i	$35°\ 34'.7$
N	$48\ \ 16$
u	$300\ .63887$

Suppose we want the apparent position at Jan'y 18*d* 18^h G. M. T.

The motion in 18 hours $= 213°.87273$, therefore for the above date $u = 154°.5116$. We also have $\alpha = 121°\ 43'$, $\delta = +\ 24°43'.3$, $\log \Delta = 9.81400$ and $\alpha - N = 73°\ 27'$. Then by (216) and (217) we find $F = 283°\ 35'\ 15''$, $\sin f = 9.99395$, $G = 329°\ 31'\ 35''$, $\sin g = 9.37089$, $F + u = 78°\ 5'\ 57''$, $G + u = 124°\ 2'\ 17''$, $\log \frac{a''}{\Delta} = 1.69601$ or $\frac{a}{\Delta} = 49''.66$ the semi-major axis of the apparent orbit. From (220) we easily find $p = 78°\ 35'\ 45''$ and $s = 48''.885$. Comparing the values of $\frac{a}{\Delta}$ and s we see that the satellite is not far from its greatest elongation, *i. e.* near the extremity of the major axis of its apparent orbit.

For the position angle of the major axis and the date of greatest elongation we find from

(225)
$$\begin{array}{rll} C = & 55°\ 33'\ 40'', & \log c = 9.99395 \\ C' = & 143\ \ 16\ \ 0 & \log c' = 9.98802 \\ C + \delta = & 80\ \ 16\ \ 59 & C' + \delta = 167°\ 59'\ 19'' \end{array}$$

Then by (226) we easily find

$\sin \theta = 9.22126$, $\theta = 9°\ 34'\ 51'' =$ the elevation of the Earth *above* the plane of the orbit.

We also find $u_0 = 164°\ 47'\ 10''$, $\cos \theta = 9.99391$
and $p_0 = 80\ \ 19\ \ 25$ $\cos \theta = 9.99391$
also $b = 8''.266$ and $\theta = 9°\ 34'\ 51''$
semidiam. of $\delta = 7\ .7$

From the values of u_0 and u and of p_0 and p we see that the satellite has not quite arrived at its greatest eastern elongation.

Then by (227) we have

$$t = T + \frac{u_0 - u}{\mu} = \text{Jan. } 18d\ 18^h + \frac{10.2755}{11.8818}$$
$$= \text{Jan. } 18d\ 18^h + 0^h.865$$
$$= \text{Jan. } 18d\ 18^h.865 \text{ G. M. T.}$$

or $$t = \text{Jan. } 18d\ 13^h.729 \text{ Wash. M. T.}$$

If we add one period or $1d\ 6^h.3$ we shall obtain the date of the next greatest eastern elongation or Jan. $19d\ 20^h.03$.

The ephemeris gives Jan. 19 21.1 which is more than an hour in error. It was probably computed from the uncorrected elements of 1879 Nov. 5, G. M. T.

The position angle and distance are about correct but the apparent orbit is not correctly delineated for the date of opposition. The satellite grazes the southern limb of the planet, the semi-minor axis being only half a second greater than the semi-diameter of the planet.

PLANET NOTES FOR MAY.

H. C. WILSON.

Mercury, having just passed inferior conjunction, will be invisible during the first part of May, but during the last days of the month may be seen toward the southeast about a half hour before sunrise. Mercury will be at greatest elongation, west from the Sun 24° 45′, on the morning of May 28.

Venus is now becoming conspicuous in the evening twilight. Venus will pass between the Pleiades and Hyades during the first days of the month and on the 18th will pass two degrees and a third north of Neptune. On the 22d, at about noon by Central Standard time, Venus will be in conjunction with the Moon, 51′ south of the latter, and to observers in high northern latitudes an occultation might be witnessed with the aid of a telescope. The phase of Venus is gibbous, nearly full, and her brightness less than one-third of that at her maximum.

Mars comes to the meridian at about half past nine o'clock in the morning and so is visible only a short time before sunrise and then in an unfavorable position.

Jupiter is now at his best for evening observation, on the meridian shortly after 9 o'clock and at his greatest northern declination for the year during May. The belts are quite vivid in coloring and the great equatorial belt, which sometimes has been nearly white, is now filled with mottled patches of light red color. The "great red spot" is seen with great difficulty and can be recognized only by the bend in the white belt north of it and the notch in the dark red belt. Its southern portion is either covered by, or merged into, the red belt which formerly has made a detour to the south as it passed by the "great red spot."

Saturn may be observed about midnight in Scorpio. This planet will be at

opposition May 30, but the declination is so far south that in this latitude observations will be possible for only a few hours of the night.

Uranus is in Scorpio, west of Saturn, near the star Beta, and can be seen at the same time with Saturn.

THE CONSTELLATIONS AT 9 P. M., MAY 1, 1898.

Neptune is too far west in the early evening for observations of any value.

The Sun has been comparatively free from spots during April. A remnant of the March disturbance came to view at the proper time, but there were only a few inconspicuous spots and on several days no spots at all were to be seen.

Jupiter's Satellites for May.

Central Standard Time.

Phases of the Eclipses of the Satellites for an Inverting Telescope.

I.

III.

II.

IV. No Eclipse

Configuration at 10h 00m for an Inverting Telescope.

Day.	West.	East.
1	4· ·3 ○ 2·	·1●
2	·4 2· 1· ○ ·3	
3	·4 ○ ·1 ·2 ·3	
4	·4 1· ○ 2· 3·	
5	○3· ·4 2· ○ 1·	
6	3· ·2 ·1 ·4○	
7	·3 ○ 1· ·4 ·2	
8	3· ○ 2· ·4	·1●
9	2· 1· ○ ·3 ·4	
10	○ ·1 ·3	·4·2●
11	1· ○ 2· 3· 4·	
12	2· ○ 3· ·1 4·	
13	3· ·2 ·1 ○ 4·	
14	·3 ○ 1· ·2 4·	
15	·3 4· ·1 ○ 2·	
16	○1· 4· 2· ○ ·3	
17	·4 ·2 ○ ·1 ·3	
18	4· 1· ○ ·2 3·	
19	·4 2· ○ ·1 3·	
20	·4 ·2 3· ·1 ○	
21	·4 3· ○ ·2 1·	
22	·3 ·4 ·1 ○ 2·	
23	2· ○1· ·4	·3●
24	·2 ○ ·4 3·	·1●
25	1· ○ ·2 3· ·4	
26	○2· ○ ·1 3·	·4
27	·2 1· 3· ○	4·
28	3· ○ ·21·	4·
29	·3 ·1 ○ 2· 4·	
30	2· ·3○ 1· 4·	
31	·2 ○4· ·3	·1●

The Moon.

		Phases.	Rises. (Central Standard time at Northfield; Local Time 13m less.)	Sets.
			h m	h m
May	5	Full Moon	7 18 P. M.	4 39 A. M.
	12	Last Quarter	12 56 A. M.	11 24 P. M.
	20	New Moon	4 16 "	8 22 "
	28	First Quarter	12 0 M.	12 50 A. M.

Occultations Visible at Washington.

Date 1898.	Star's Name	Magnitude.	IMMERSION. Washington M. T. h m	IMMERSION. Angle from N pt. °	EMERSION. Washington M. T. h m	EMERSION. Angle from N pt. °	Duration. h m
May 6	3 Scorpii	6.7	12 6	118	13 22	270	1 16
10	σ Capricorni	5.6	16 29	6	17 12	303	0 43
24	79 Geminorum	6.3	9 25	52	9 54	350	0 29

Phenomena of Jupiter's Satellites.

Central Standard Time.

		h	m				h	m			
May	1	8	2 P. M.	I	Oc. Dis.		10	11 P. M.	III	Ec. Re.
		11	3 "	I	Ec. Re.		11	12 "	I	Tr. Eg.
		11	51 "	II	Tr. In.	17	12	14 A. M.	I	Sh. Eg.
	2	1	31 A. M.	II	Sh. In.		9	21 P. M.	I	Ec. Re.
		2	24 "	II	Tr. Eg.		11	35 "	II	Oc. Dis.
		7	35 P. M.	I	Tr. Eg.	18	6	43 "	I	Sh. Eg.
		8	25 "	I	Sh. Eg.	19	7	58 "	II	Sh. In.
	3	6	47 "	II	Oc. Dis.		8	20 "	II	Tr. In.
		11	0 "	II	Ec. Re.		10	30 "	II	Sh. Eg.
	5	10	0 "	III	Tr. In.	23	6	59 "	III	Oc. Dis.
	6	12	45 A. M.	III	Tr. Eg.		9	49 "	III	Oc. Re.
		1	35 "	III	Sh. In.		10	47 "	I	Tr. In.
	8	12	41 "	I	Tr. In.		11	43 "	III	Ec. Dis.
		1	36 "	I	Sh. In.		11	52 "	I	Sh. In.
		2	56 "	I	Tr. Eg.	24	1	2 A. M.	I	Tr. Eg.
		9	49 P. M.	I	Oc. Dis.		7	55 P. M.	I	Oc. Dis.
	9	12	58 A. M.	I	Ec. Re.		11	15 "	I	Ec. Re.
		7	8 P. M.	I	Tr. In.	25	7	30 "	I	Tr. Eg.
		8	4 "	I	Sh. In.		8	38 "	I	Sh. Eg.
		9	23 "	I	Tr. Eg.	26	8	12 "	II	Tr. In.
		10	20 "	I	Sh. Eg.		10	33 "	II	Sh. In.
	10	7	36 "	I	Ec. Re.		10	47 "	II	Tr. Eg.
		9	10 "	II	Oc. Dis.	27	1	5 A. M.	II	Sh. Eg.
	11	1	37 A. M.	II	Ec. Re.	28	8	9 P. M.	II	Ec. Re.
	12	7	55 P. M.	II	Sh. Eg.	30	10	42 "	III	Oc. Dis.
	15	11	38 "	I	Oc. Dis.	31	9	46 "	I	Oc. Dis.
	16	7	44 "	III	Ec. Dis.		10	41 "	IV	Tr. In.
		8	57 "	I	Tr. In.		11	53 "	IV	Tr. Eg.
		9	59 "	I	Sh. In.					

Ec. Dis. = Eclipse disappearance; Ec. Re. = Eclipse reappearance; Oc. Dis. = Occultation disappearance; Oc. Re. = Occultation reappearance; Sh. In. = Ingress of shadow upon disc of planet; Sh. Eg. = Egress of shadow from disc; Tr In. = Ingress of satellite in transit across disc of planet; Tr. Eg = Egress of satellite.

COMET NOTES.

Elements and Ephemeris of Comet *b*, 1898.—I have computed the following system of elements using my observations of March 19, 22 and 26.

$T = 1898$ March $16^d.79123$.

	°	′	″	
ω	46	57	11.6	Ecliptic and mean Equinox of 1898.0
Ω	262	18	53.1	
i	72	21	14.4	

log *q* 0.040024

RESIDUALS FOR THE MIDDLE PLACE.

$O-C$	$\Delta\lambda' \cos\beta'$	$+0''.3$
	$\Delta\beta'$	$-0''.3$

CONSTANTS FOR THE EQUATOR OF 1898.0.

$$x = r\,[9.516976]\,\sin(v + 22^\circ\ 57'\ 23''.6)$$
$$y = r\,[9.999997]\,\sin(v + 292^\circ\ 20'\ 32''.3)$$
$$z = r\,[9.975153]\,\sin(v + 22^\circ\ 16'\ 3''.6)$$

EPHEMERIS FOR GREENWICH MEAN MIDNIGHT.

1898	True α	δ	log r	log Δ	Br.
	h m s	° ′			
April 7.5	22 33 56	+ 35 0.5	0.0617	0.2099	0.87
11.5	22 52 37	38 25.2	0.0697		
15.5	23 12 8	41 32.3	0.0787	0.2262	0.75
19.5	23 32 24	44 20.3	0.0885		
23.5	23 53 18	46 48.6	0.0989	0.2474	0.62
27.5	0 14 38	48 57.1	0.1098		
May 1.5	0 36 14	50 46.0	0.1211	0.2714	0.50
5.5	0 57 54	52 16.5	0.1327		
9.5	1 19 24	53 29.9	0.1445	0.2963	0.40
13.5	1 40 31	54 27.8	0.1564		
17.5	2 1 7	55 12.0	0.1684	0.3210	0.32
21.5	2 20 58	55 44.2	0.1803		
25.5	2 40 0	56 5.9	0.1922	0.3444	0.26
29.5	2 58 8	56 19.0	0.2040		
June 2.5	3 15 18	+ 56 24.8	0.2156	0.3660	0.21

Brightness at discovery taken as unity.

C. D. PERRINE.

LICK OBSERVATORY, University of California.
1898 March 31.

VARIABLE STARS.

J. A. PARKHURST.

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time.]

1898.

U CEPHEI.

	d	h
June	5	13
	10	13
	15	13
	20	12
	25	12
	30	12

δ LIBRAE.

	d	h
June	9	15
	16	14
	23	14
	30	14

RS SAGITTARII.

	d	h
June	4	18
	9	14
	14	9
	16	19
	21	15
	26	11
	28	21

U CORONÆ.

	d	h
June	14	15
	21	12
	28	10

U OPHIUCHI.

Every 10th min.
$P = 20^h.1$

	d	h
June	2	22
	11	7
	19	17
	28	12

W DELPHINI.

	d	h
June	12	18
	17	13
	22	9

Y CYGNI.

Even min.

	d	h
June	1	12
	4	12
	7	12
	10	12
	13	12
	16	11
	19	11
	22	11
	25	11
	28	11

Odd min.

	d	h
June	2	15
	5	15
	&c to	
	29	15

Maxima and Minima of Long Period Variables.

1898 July.

MAXIMA.

		m	day
893	U Ceti	7	3
1981	S Camelopardalis	8.5	29
2266	V Monocerotis	6.5	26
3244	S Pyxidis	8.5	3
4315	R Comae	7.5	19
4521	R Virginis	7	31
4816	V Virginis	8.5	13
5190	R Camelopardalis	8	26
5338	U Bootis	9.5	30
5430	T Librae	9.5	8
5644	Z Librae	11	13
6449	T Draconis	8	24:
6923	Z Sagittarii	8.5	10
7404	R Microscopii	8	11
7659	T Capricorni	9	21
7813	R Gruis	8.5	5
8040	S Gruis	7	19
8068	S Lacertae	8	22

MINIMA.

		m	day
146	T Sculptoris	11	13:
401	U Sculptoris	< 12	—
419	U Andromedae	< 13	—

MINIMA, CONTINUED.

		m	day
845	R Ceti	13	10
1386	T Eradani	11	—
1717	V Tauri	< 13	23
2539	R Canis minoris	10	9:
3637	S Carinae	9	30
4407	R Corvi	< 11	—
4492	Y Virginis	12	13:
4511	T Ursae Majoris	12.5	4
4557	S Ursae Majoris	11	21
4596	U Virginis	12.5	18
5237	R Bootis	12	14
5566	RU Librae	< 12	—
5795	W Scorpii	< 14	9
5830	R Scorpii	< 13	—
6132	R Ophiuchi	< 12	—
6849	R Aquilae	11	2
6905	R Sagittarii	12.5	23
6943	T Sagittae	9.5	6:
7260	Z Aquilae	11	—
7266	RT Sagittarii	< 11	—
7456	RR Cygni	9.5	—
7560	R Vulpeculae	13	29
7907	U Aquarii	14	—
7909	S Piscium aust.	< 11	—

The above ephemeris is based on the elements of Chandler's Third Catalogue and supplements, except for Y Cygni, which depends on Dunér's revised elements. The times for the Algol type stars are taken from Dr. Hartwig's ephemeris in the *Vierteljahrsschrift*, except for RS Sagittarii, U Ophiuchi and Y Cygni. The times for the long period stars are from Dr. Chandler's ephemeris in *Astronomical Journal* No. 420.

NOTES.

Mr. C. E. Peek, director of Rousdon Observatory, Lyme Regis, Eng., has lately published a valuable paper entitled "Variable Star Notes, No. 3, S Cassiopeae and S Ursae Majoris, 1887-1896." This paper contains his individual observations of these two northern variables for the ten years, each star being observed once or twice (occasionally three or four times) every month in the year. The introduction says—"Each observation consists of the mean of five visual comparisons with stars whose magnitudes have been previously determined, either by myself or by some other observer. All comparisons are made with stars in the same field of view as the variable. Instrument in use, 6.4 inch equatorial refractor by Merz." There are given 256 observations of S Ursae Majoris in the ten years, an average of one in two weeks. These include 16 maxima and the same number of minima, the limiting magnitudes being 7.5 and 12.5. In the same interval of time there are 216 observations of S Cassiopeae, an average of one in 17 days; including 6 maxima and 6 minima, between the magnitudes 8.0 and 13.5. Following the detailed observations are graphic representations of the light curves. All together the paper is a good example of what reports of variable star observations ought to be in order to be of lasting value. Mr. Peek's observations of S Cassiopeae are of great interest in one particular. On 12 different occasions he remarks something like the following: "Deep red, hazy, ill-de-

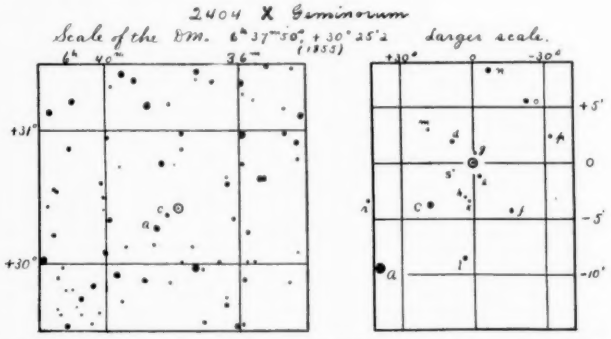
fined as if surrounded by an atmosphere." "A very hazy red star." "Surrounded by a ruddy haze." "Deep orange, a well defined star surrounded by a ruddy atmosphere." These observations are exceedingly interesting from the following considerations:

(1) Professor Myers' researches on β Lyrae (April number, page 117) show that variable to be in a nebulous condition.

(2) The variable Mira, when near maximum, shows bright hydrogen lines in its spectrum, an indication of an immense glowing hydrogen atmosphere.

(3) Spectroscopic observations of the "new stars", T Aurigae and R Normæ, show that each changed to a nebula at a certain stage of development.

Without attempting to explain the relation between these facts, they certainly give us food for thought, and perhaps point towards the conclusion that variability in stars is an atmospheric phenomenon.



ANDERSON'S NEW VARIABLE IN GEMINI. The variability of this star, which is DM.30, 1329 was noted in Vol. V, page 556 of POPULAR ASTRONOMY. In No. 3463 of the *Nachrichten* Anderson reports that the star was $8^m.7$ about the middle of March 1897, and had fallen to $10^m.3$ April 30. On Nov. 28 he found the variable $8^m.3$. I found it $9^m.1$ 1898 Jan. 4, after which time it fell to 11.8 Mar. 13 and rose to 11.0 April 7, the last comparison. The minimum is indicated for March 7, by the 14 observations.

The following comparison stars appear on the accompanying chart.

	Co-or. from V. R. A.		Decl.	
	s	′		m
p	− 32 5	− 7 0	+ 2 5	10.8
o	− 22.6	− 4.9	+ 5.8	10 0
f	− 16.3	− 3 5	− 4.1	10.8
n	− 6.3	− 1.4	+ 8.4	10.3
e	− 3.4	− 0.7	− 1.2	10.8
g	− 0.5	− 0 1	+ 0.9	11.4
k	+ 1.1	+ 0.2	− 3.3	12
l	+ 3.3	+ 0.7	− 8.6	10
h	+ 3.7	+ 0.8	− 2.9	11.9
s	+ 9.3	+ 2.0	− 1.1	12.7
d	+ 8.8	+ 1.9	+ 1.9	10.0
c	+ 17.8	+ 3.8	− 3.8	9.6
m	+ 18.6	+ 4.0	+ 3.0	11
a	+ 39.2	+ 8.4	− 9.5	7.8
r	+ 43.4	+ 9.4	− 3.3	10.7

A comparison between Anderson's observations and mine suggest a period of about 9 months.

ANDERSON'S NEW VARIABLE IN LYNX, charted in the April number, page 118, has a $12^m.5$ companion in position angle 155°, distance 12″.6, kindly measured by Professor E. E. Barnard with the Yerkes 40-inch. The variable is now (April 10) a little fainter than the companion, so that a large aperture, 10 or 12 inches, is needed to follow it through the minimum.

It is only just to say of the chart in the April number that it was not drawn for publication, but to aid in identifying the variable at the Goodsell Observatory, that the companion might be measured with the 16-inch telescope.

GENERAL NOTES.

Photograph of the Total Solar Eclipse 1898 Jan. 21-22.—We have just been favored by Professor J. M. Schaeberle with a positive from a photograph of the total solar eclipse taken by Professor W. W. Campbell who was in charge of the Lick Observatory expedition and whose station was at Jeur, India. It is a fine picture of the interior corona with an exposure of ten seconds and was taken with the Floyd photographic telescope. It will be reproduced in our next number.

Professor J. M. Schaeberle has resigned his position as astronomer at the Lick Observatory. He has been acting Director of the Observatory since the resignation of Professor Holden. The Regents of the University of California have accepted Professor Schaeberle's resignation to take effect one year hence, with leave of absence in the mean time on full pay. This information comes through the San Francisco papers, and is doubtless reliable. The Board of Regents have done handsomely by Professor Schaeberle in regard to leave of absence and pay.

American Association for the Advancement of Science.—The fiftieth anniversary of the American Association for the Advancement of Science will be celebrated in Boston, Aug. 22-27, 1898.

Officers of the Boston Meeting:—F. W. PUTNAM of Cambridge, President and Permanent Secretary; E. E. BARNARD of Yerkes Observatory, Williams Bay, Vice President, Section A Mathematics and Astronomy; F. P. WHITMAN of Adelbert College, Cleveland, Vice President Sec. B Physics; E. F. SMITH of University of Penna. Philadelphia, Vice President Sec. C Chemistry; M. E. COOLEY of the University of Michigan, Ann Arbor, Vice President Sec. D, Mechanical Science and Engineering; N. E. FAIRCHILD of University of Rochester, Rochester, Vice President Sec. E, Geology and Geography; A. S. PACKARD of Brown University, Providence, Vice President Sec. F. Zoology; W. G. FARLOW of Harvard University, Cambridge, Vice President Sec. G, Botany; J. McK. CATTELL of Columbia University, New York, Vice President Sec. H, Anthropology; ARCHIBALD BLUE of Toronto, Vice President Sec. I, Social and Economic Science; L. O. HOWARD of Washington; D. S. KELLICOTT of Columbus; FREDERICK BEDELL of Ithaca; ALEXANDER ZIWET of Ann Arbor (*resigned*); E. B. ROSA of Middletown (*resigned*); CHARLES BASKERVILLE of Chapel Hill; W. S. ALDRICH of Morgantown; WARREN UPHAM of Saint Paul; C. W. STILES of Washington (*resigned*); E. F. SMITH of Washington; M. H. SAVILLE of New York; MARCUS BENJAMIN of Washington; R. S. WOODWARD of New York.

Tuttle's Comets.—Mr. H. P. Tuttle refers in the March number of POPULAR ASTRONOMY to Schulhof's determination of elliptic elements of Comet III 1858 which was discovered by himself on May 2. This he says was published in *Astronomische Nachrichten* but he does not give the number. Perhaps therefore I may supply it: No. 2592 (vol. cviii, col. 425) as well as that (No. 2599, vol. cix, col. 111) which gives an account of Spitaler's attempt to observe the comet at Vienna in 1884. Hind's article on the subject in *Nature* appeared on July 10, 1884, and the *Observatory* for that year also gives a very full report of the matter, (vol. vii pp. 172, 240). It seems possible that Spitaler obtained one position of the comet on May 26, which in that case would be on the fourth return after the appearance of 1858, and another should have taken place towards the end of last year.

Mr. Tuttle speaks in his article of twelve comets which he has discovered. Would he kindly give a list of them, as all that I have been able to find are four, viz, I 1858, III 1858, VII 1858, and III 1861. As I mentioned in the '*Observatory*' for December last, he was also the first to perceive Donati's comet (VI 1858) though he did not announce it until he had obtained an accurate position, and was in the meantime anticipated by the Italian astronomer. Mr. H. P. Tuttle was an independent discoverer of Comet III 1862 (connected with the Perseid meteors), but Professor Swift (as afterwards appeared) was the first; and on January 26, 1875, was the first to perceive Encke's comet at that return, when an observation was made by Professor Holden. W. T. LYNN.

Blackheath, London, England.
1898, April 4.

Professor J. E. Keeler Director of Lick Observatory.—On April 2, Professor Keeler decided to accept the position of director of the Lick Observatory, Mount Hamilton, California, to which he was elected some time ago, and so telegraphed to the President of the Board of Regents of the University of California.

In making the choice of a man for this important position, the New York *Tribune* well says, the Regents were somewhat embarrased by the abundance of good material at their disposal, and that they recognized the natural and proper sentiment of many, that a successor to Professor Holden could be found on the Pacific Coast. The two men in this relation to the Observatory were Professor J. M. Schaeberle and Professor George Davidson. Professor Schaeberle is now the oldest man in service on the staff at Lick Observatory. He is an able astronomer and is one of the most consciencious and faithful scholars known to American astronomy. He has achieved this reputation while still in middle life and the promise of usefulness to the science he loves is still great.

Professor George Davidson is now upwards of seventy years of age, has been in the service of the United States Coast and Geodetic Survey, for many years, during which time he has done a great variety of useful and important astronomical work. Very naturally he was invited some time ago to occupy a chair in the University of California, which he has filled very creditably. It is not a wonder that Professor Davidson should have come very near being elected to the directorship of Lick Observatory under the circumstances.

Professor James E. Keeler who was finally chosen has not yet quite completed his forty-first year, but he has won in his early life a world-wide distinction in spectroscopic research. This has been possible on account of general scholarship in science, as well as peculiar strength in spectroscopy. We doubt if any person

can have as permanent and useful attainments in a single branch, as is possible when the scholarship includes at least a group of branches belonging to the same general theme. In the *N. Y. Tribune* of March 20 we find the following sketch of Professor Keeler:

"While in Johns Hopkins University (1877-1881) this amateur astronomer's tastes and ambitions were stimulated in a variety of ways. Through the kindness of Charles H. Rockwell, of Tarrytown, N. Y., he was enabled to take part in the solar eclipse expedition which went to Colorado in 1878, under the direction of Professor Holden. In the spring of 1881 Professor Langley (whom Mr. Keeler afterward succeeded as director of the Alleghany Observatory) gave a series of lectures at Johns Hopkins, and at that time he had the assistance of the young enthusiast, in whom, no doubt, he even then recognized a kindred spirit. Later in the season, even before his formal graduation, Mr. Keeler was enlisted by Professor Langley in the famous Mount Whitney (Cal.) expedition for the study of solar physics."

"The next year or two were spent abroad, working with Quincke in Heidelberg and Von Helmholtz in Berlin. He carried out an investigation of the "Absorption of Radiant Heat by Carbon Dioxide" with a bolometer which Professor Langley had given him, in which Helmholtz was greatly interested."

"Returning from Germany, he was occupied in various researches under Professor Langley's direction, until, at Professor Holden's instance, he was appointed astronomical assistant by the Lick trustees in April, 1886. In June, 1888, when the Observatory was transferred to the state, he became "an astronomer to the Lick Observatory," with spectroscopy as his special department. He also had charge of the time service, afterward with the aid of an assistant. With the 36-inch telescope and a spectroscope which Brashear made from Professor Keeler's drawings, he measured spectra of stars and planets and discovered and measured the motions of the nebulæ. This last may be his best work on Mount Hamilton."

"The directorship of the Allegheny Observatory was offered to him in 1889 when Professor Langley went to Washington as secretary of the Smithsonian Institution. The post was accepted, and shortly afterward Professor Keeler was married. At Allegheny his work has been almost exclusively in the line of stellar spectroscopy. He has succeeded in getting many excellent photographs in that part of the spectrum where the rays have less actinic value than in the violet region. However, the smoky air of Pittsburg and its great suburb is not especially favorable to undertakings of this kind. With the better atmosphere and instruments on Mt Hamilton much more satisfectory results can, of course, be secured. Professor Keeler's determination with the spectroscope of the fact that Saturn's ring is composed of small, detached particles (undoubtedly meteoric), and his investigations of the relations between the spectra of the nebulæ and stars in Orion have been features of his most recent work. He has written and lectured somewhat extensively, too, on his own researches and kindred topics."

"Besides his A. B. from Johns Hopkins, Professor Keeler received the degree of Doctor of Science from the University of California, "honoris causa," in 1893. He is a member of numerous American and foreign scientific societies, among them the Royal Astronomical Society of Great Britain."

The friends of Professor Keeler made a strong effort to meet the conditions which he named, as desirable and really necessary to pursue astronomical work properly at Alleghany Observatory. Although the conditions were not fulfilled good progress was made in that direction, and when he goes to Mount Hamilton, which will be about the middle of this month, he will leave behind a host of friends still loyal and enthusiastic in his praise as ever.

Remarks upon Dr. See's Article.—I have just read with much interest Dr. See's article in the April number of POPULAR ASTRONOMY, on the "Astronomical climate" of different countries. Although I have not had the privilege of visiting so many places as Dr. See and although a "Colorado blue" is the nearest I have ever seen to an "Arizona blue," yet I can say, amen, to many of the statements made by him.

During a year's stay in Germany I learned to appreciate even the ordinary climate which we have in these central United States. I did not attempt any observations while there but had a photographic apparatus with me and waited and waited for some decent weather but it came not. Of all the negatives made there are not half a dozen good ones. It was rather discouraging for just previously I had taken, in the clear mountain climate of Oregon, fifty-six fine negatives with five dozen plates. In Munich there are only between thirty and forty entirely clear nights in the year and between ninety and one hundred in which *some* observations can be made.

Dr. See's article is perhaps a trifle misleading in one respect. He dwells at some length upon the *blueness* of the sky in Arizona. Yet no one knows better than he does, and I am sure he did not intend to convey any other impression, that it is the *steadiness* and not the *blueness* of the Arizona atmosphere that makes the seeing there superior to that in other places, and blueness is not necessary to steadiness and is in no sense a safe criterion of steadiness. The most perfect view that I ever obtained through a telescope was one morning in October or November, 1889, while looking at Saturn with the 15-inch equatorial at the Washburn Observatory. The sky was far from blue. The valleys below had gradually filled with fog; it had even reached up and enveloped the dome of the Observatory; everything was reeking wet with moisture; but there was not a breath of air stirring and I was not a little astonished upon looking into the telescope to see a perfectly steady image of the planet; a view such as I had never seen before and such as I have never seen since. I enjoyed it for only a few moments, however, for the fog soon became so thick as to shut out entirely the light of the planet.

Again in January, 1893, at the Lick Observatory, while making some spectroscopic observations with the 36-inch telescope, I attempted to observe one clear night. The sky that day had been of an irreproachable blueness—in fact I venture to think of almost an Arizona blueness—but alas the atmosphere was moving by at the rate of fifty-five miles an hour. It is not difficult to imagine the weight to be attached to the observations then made.

There is one other point touched upon by Dr. See that needs emphasis, for the importance of considering it seems not yet to be impressed upon the minds of Observatory makers. Some ten years ago while a student at the University of Wisconsin I became convinced that the ordinary methods of covering up both equatorials and transits is essentially wrong. The less covering the better. In order to obtain the best seeing it is necessary that the conditions within the observing room should be as nearly as possible the same as those outside. This is *not possible* if the telescope is surrounded with stone and iron. If you must have a house for your transit or meridian circle then it should be so constructed that the *whole* roof can be thrown off and not merely a narrow slit opened. The sides should be constructed of some light material, and the more of the sides that can be taken away or opened during observations so much the better.

If it is necessary to build the equatorial dome of heavy material, then as much as possible of the lower portion should be windows, and a good construction for the dome itself is to build it in two halves one of which revolves within the other

thus exposing half the sky at one time. Such a dome was constructed several years ago for the 6-inch equatorial of the Washburn Observatory and has been found to work very satisfactorily. A cut of it is in the Washburn Observatory Publications Vol. 9 opposite page 6. It will be argued that these constructions will not protect the telescope from the wind. But I venture to suggest that astronomy would now be in a more advanced state, if nine-tenths of the observations made when the wind was blowing sufficient to sway a telescope, had never been made. There can be no doubt but that the "ideal dome is that of the heavens itself."

SIDNEY TOWNLEY.

Telegrams of Announcement and Discovery.—Many of our readers doubtless know of the system of telegraphic announcement of important astronomical news and discovery. After years of trial the system, so far as we know, is very satisfactory. Its central bureau is at Harvard College Observatory under the immediate management of Mr. J. Ritchie, Jr., who also publishes the *Science Observer* circulars. No. 117 gave the orbit and ephemeris of Comet *b* 1898, (Perrine). March 24 we sent a position of Perrine's Comet for that day taken at Goodsell Observatory by Dr. H. C. Wilson. In Mr. Ritchie's prompt reply we learned what we did not know before, how telegrams should be addressed in order that they may reach the central bureau at earliest possible moment. We give a portion of Mr. Ritchie's letter relating to this point:

"To get a little better and surer service with telegrams like that of yours which are intended to benefit astronomers in general at the earliest moment, I have concluded to assume for these messages the same address as for those from the Centralstelle in Kiel, viz., *Astronomer, Boston, Mass.* According to a system which I have used for about fifteen years the messages so addressed are delivered to a Messenger company which makes duplicates and forwards them to a number of different addresses, so that the fact of my not being at my house does not delay at all the use or distribution of the position or discovery. In case I am away from home, out of the city, the other persons in the system being notified and knowing me to be away are ready to act in my place. By this safeguard I think that there has not been an hour's loss of time, when time was of any importance, since the system of distribution was established. I should be glad to have American astronomers use this address since it means better and surer service."

"The program of Lick Observatory on the discovery of a comet is to get three observations as soon as possible and compute an orbit, and send the whole thing right along by telegraph. In two or three hours after the receipt of the message I print the circular. So plainly there is not much time lost and it is a little hard for anyone besides Lick to get in their say. But all the same I am glad to have the spirit and interest shown that has been shown by your institution a number of times, and wish to assure you that these efforts are not thrown away."

Catalogue of 500 New Double Stars Discovered at the Lowell Observatory.—*The Astronomical Journal*, Nos. 431-2 contains Dr. See's catalogue of 500 new double stars, which will always be ranked as a noble contribution to the subject. The space available for these notes will not permit an adequate review of this important work; the best review is for the reader to consult the catalogue itself, in which the author appears at his best. Until Dr. See joined the Lowell Observatory it might have been supposed that a mathematician

would not specially distinguish himself as an observer; such a view, if it was ever held, has been totally disproved by events, for Dr. See has unquestionably shown himself one of the most distinguished observers in the world, a worthy successor of the Herschels. We learn from the catalogue that in the course of the sweeps which resulted in the discovery of 500 new double and multiple stars, Dr. See and his assistants, Mr. Cogshall and Mr. Boothroyd, *examined carefully over 100,000 stars brighter than 10th magnitude.* The region swept over includes nearly the whole zone between — 20° and — 45°, and the more southern region between — 45° and — 65°, and the hours of right ascension 4 and 16. It is easy for one to imagine that the work embodied in this catalogue represents an immense labor; yet there is no expression in the catalogue to indicate the energy and tireless zeal which the observers must have possessed to execute so great a work in so short a time. It is safe to say that this survey at the Lowell Observatory breaks all records. It is in every way a distinguished contribution, and one that does great honor to the Lowell Observatory and to America, which for some years has led in the cultivation of Stellar Astronomy. It is chiefly Mr. Burnham whom we may thank for keeping alive public interest in these researches, and more recently Dr. See for the greatly renewed interest arising from his investigations in stellar evolution.

The catalogue contains:

31	stars	below	0″.25			in width.
45	"	between	0	.25	and	0″.50.
46	"	"	0	.50	and	1 .00.
122	"	below	1	.00		
40	"	between	1	.00	and	2 .00.
86	"	"	2	.00	"	5 .00.
94	"	"	5	.00	"	10 .00.
129	"	"	10	.00	"	25 .00.
29	"	separated by more than 25″ 00.				

Many of these stars are bright, and some of them are among the most important systems known.

About eight objects are described as shining with a dull luster, as if by reflected light. Some of these dull companions are believed to be the most difficult stars which have ever been discovered. It is thus clear that the catalogue is a work of the highest significance, and will always be so regarded. Such discoveries as η Centauri, α Phoenicis, θ Scorpii, d Centauri, p Velorum, λ Lupi and other bright and close pairs, in which the catalogue abounds, seldom fall to the lot of any man, and may indeed be ranked among gems of the sky. POPULAR ASTRONOMY warmly congratulates her distinguished young contributor, on a work which constitutes a veritable "monumentum aere perennius."

The Concise Knowledge Library—Astronomy, by Agnes M. Clerke, A. Fowler, J. Ellard Gore, xvi + 581 pages, leather and cloth, $2.00, D. Appleton & Co., New York.

This book, according to the preface, "aims to present in concise form a popular synopsis of astronomical knowledge to date." It does so in 581 well-filled pages comprising four sections.

Section I (pages 1-38) on the History of Astronomy from Hipparchus to 1897; and Section III (pages 227-396) on the Solar System, are by the popular and talented Miss Agnes Clerke. Both these sections are written in her usual clear, concise, sprightly style. We might remark that it is not quite right to say (page 8)—as many others before her have said—that "Tycho Brahé was sum-

moned to astronomy by a star—the marvellous 'new star' of 1572," since Gassendi,* to whom we all must go for first statements about Tycho, expressly says that twelve years earlier Tycho's love for astronomy was engendered by the fulfilment of the prediction of a solar eclipse, August 21, 1560, when he was only fourteen years old. Indeed, long before 1572, Tycho had built a large sector at Augsburg and he carried it with him when he returned to Denmark. His observations of the star of 1572 were made with that instrument which he thus had ready at hand.

The usually accepted year of Kepler's birth is 1571, not 1573 (page 10). On page 37, in the line "Dr. Gould's determination from his plates of nearly fifty stars in the Pleiades" the word "his" should be replaced by "Rutherfurd's" and four lines lower put "reductions" in the place of "measures."

There is a certain lack of unity between the various sections of this book. Miss Clerke states (page 3) that the first star-catalogue ever constructed contained 1080 stars, while Mr. Fowler (page 71) says 1022. Of course Miss Clerke is correct. And the last star-catalogue ever constructed without telescopic aid to vision—I refer to that of Hevelius—contains 1888 stars, not merely 1553 (page 71). For the importance of this erratum, see the article on Women Astronomers, POPULAR ASTRONOMY, this number. And while Miss Clerke says (page 38) seventeen Observatories are taking part in the astrophotographic charting, Mr. Fowler "goes her one better" on page 71. Moreover the figures in each section are numbered independently instead of continuously. These are all small matters but they might have been avoided.

It is so seldom that books of this class in astronomical literature present a sketch of the development of the science by a distinct historical section that one can be contented for the brevity of Section I only by the thought that there *had* to be a limit to the number of pages which the generosity of the publishers could bestow upon the purchaser for the low price of this Concise Series—and there were so many other interesting things to tell about!

Mr. Fowler takes up some of these in Section II (pages 41-226) which is on Geometrical Astronomy. The title might scare some readers, but there is very little mathematics, and that little put so simply that "he who runs may read." Again we would take exception to only page 124: The description of Talcott's method of using the zenith telescope for determination of latitude shows decidedly a lack of experience with that instrument.

Section IV (pages 397-565) is by Mr. Gore. This section deals with the Sidereal Heavens. The author shows an extensive acquaintance with binary systems (chap. iv) as one would naturally expect of the editor of "*Double Stars*;" and with variable and temporary stars (chap. v): with clusters and nebulæ (chap. vi): and, we might add, some pretension to the Arabic language; but we have been wondering if he would have us believe that Al-Sûfi, the Persian astronomer of the tenth century really wrote about the redness of Algol in nineteenth century *French* (page 472)!

We notice only two really serious blunders in the book: page 202 "as an illustration of a modern meridian circle we select that of the Lick Observatory, Fig. 53;" while on the opposing page, under the illustration we read the following legend: "Fig. 53—The Meridian Circle of the Paris Observatory." As the cut is so nearly identical in every detail with one which the reviewer clipped from the *Illustrated Christian Weekly* over sixteen years ago, one is inclined to think the legend is correct and the text doubly erroneous. The other blunder is in

* *De Tychonis Brahei Vita*, Liber primus, p. 5.

the confusion of "maximum" and "minimum" on page 459: of course a variable star is at its maximum when it is brightest.

It would not be without interest (at least to the present reviewer) to know what astronomer is responsible for the parallax of .465 given for Eta Cassiopeiæ on pages 422 and 450. Entirely too much prominence is given to conclusions arrived at from photographic measures by Pritchard (pages 422, 424, etc.) in view of their untrustworthiness.*

Of course a number of advances have been made while the book was in press: 1830 Groombridge is no longer the "runaway" star (page 424): the Yerkes telescope is now in active service (page 189): the parallax of 61 Cygni has been shown, by both Wilsing and Davis, to be nearer ".36 than ".50 (page 427) or ".45 (page 222), and very grave suspicion has been entertained by Davis regarding the probability that 61 Cygni is a binary system.* No mention is made of Wilsing's claim that it is a triple system.

But on the whole Section IV forms a fitting conclusion to what was so ably begun by Miss Clerke in Section I. And the very fewness and (for the most part) insignificance of the above criticisms is the surest indication of the excellence of the book in general. It is a good book for the class-room; a charming book for general readers; but best adapted to start an interest for astronomy with those who have not yet felt a drawing towards the starry realms of night, nor heard the music of the spheres. H. S. D.

The *Atlantic Monthly* for October 1897 contains an article by Dr. See on "Recent Discoveries Respecting the origin of the Universe," which is of much interest to astronomical as well as general readers. It attracted wide-spread attention, and is certainly a notable contribution to our literature. In the April number of the *Atlantic* just at hand Professor G. H. Darwin, who stands at the head of English Astronomy, has an important paper supplementing Dr. See's article. The *Atlantic* is very fortunate in securing papers which are of interest even to astronomers. Such contributors as it has secured with the last year, Lowell, See, and Darwin, make it the quite astronomical, as it also of the best of our great magazines.

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* *Contribution from the Observatory of Columbia University*, No. 13.